ELEMENTS

OF

GEOLOGY.

BY

CHARLES LYELL, ESQ. F.R.S.

VICE-PRESIDENT OF THE GEOLOGICAL SOCIETY OF LONDON, ETC.;
AUTHOR OF "PRINCIPLES OF GEOLOGY."

"It is a philosophy which never rests—its law is progress: a point which yesterday was invisible is its goal to-day, and will be its starting post to-morrow."—EDIN. REV., No. 132. p. 83. July 1837.

Second Edition.

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1841.

TO

WILLIAM HENRY FITTON,

M.D. F.R.S.

VICE-PRESIDENT OF THE GEOLOGICAL SOCIETY,

ETC.

MY DEAR DR. FITTON,

I HAVE great pleasure in re-dedicating this work to you, as a memorial of an uninterrupted friendship of more than twenty years, during which we have been engaged in the same scientific pursuits. I am also glad to have this opportunity of acknowledging the benefit which my writings have so often derived from your friendly criticism.

I am,

My dear Dr. Fitton,

Yours, very sincerely,

CHARLES LYELL.

LONDON, *July* 10. 1841.

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PREFACE.

Since the appearance of the First Edition of this Work, I have published a new or Sixth Edition of the "Principles of Geology," omitting altogether that portion contained in previous editions, in which the European tertiary formations were described in some detail. The part thus omitted has, with considerable modifications and corrections, been incorporated in the present edition of the "Elements," so that the two works now occupy very distinct ground; the "Principles" being chiefly confined to those modern changes of the earth and its living inhabitants which are illustrative of Geology, while in the "Elements" I treat of the component materials of the earth's crust considered as the monuments of the successive revolutions through which this globe and its inhabitants have passed in times antecedent to the creation of man.

When I observe that the "Principles of Geology" are *chiefly* confined to the modern changes of the organic and inorganic world, I wish to remind the student that I have prefixed to my systematic account of those changes a series of Essays (comprised in the First Book), in which I have endeavoured to explain those general and theoretical conclusions which the numerous facts now brought to light by geology have led me to adopt, and on which I have not deemed it expedient to enlarge in an elementary work like the present.

I have often been asked which of the two treatises I intend to be read first by one who is willing to study both. In answering this question, I experience much the same difficulty as if asked whether a beginner should take up first a treatise on Chemistry or one on Natural Philosophy, subjects so distinct, and yet so inseparably connected. Upon the whole, I am inclined to think that those students who are entirely unacquainted with the subject will do well to peruse the "Principles" first, as their curiosity may be thus excited by entering at once on the sketch which has been given of the progress of opinion in geology from

strata — trap-rocks of the Carboniferous period — granites of Arran.

N.B. The greater part of the woodcuts in this volume are the work of Mr. James Lee, 97. Prince's Square, Kennington. The original drawings in Natural History were done chiefly by Mr. Geo. Sowerby, jun., 10. College Terrace, Cambden New Town.

ERRATUM.

Page 343. line 5. from bottom, for "*Dichobune*" read "*Dichobunes.*"

the earliest times, and by a discussion of the many questions of general interest to which the examination of the earth's structure gives rise; such as the causes of former changes of climate, — the extinction of species, — the supposed progressive developement of organic life, — the recent origin of man, — the analogy or want of analogy between the igneous and aqueous causes formerly operating and those now in action, and a variety of others which I cannot here enumerate. A perusal of the Second Book of the "Principles" will prepare the reader to comprehend the method of interpreting and classifying geological phenomena, by considering the *recent* effects of inorganic causes, such as rivers, springs, tides, currents, and subterranean heat, whether exhibited in the volcano or earthquake. The concluding part of the same work will give him an insight into the changes which the organic world has undergone in modern times, by explaining the laws which govern the present geographical distribution of the various species of animals and plants, the causes of their multiplication and extinction, and the manner in which their remains become fossil in new deposits.

But, however intimate their connection, the two treatises are now entirely independent of each other, so that either of them may be taken first in order. I have not repeated in this work a glossary of geological terms which I inserted in the "Principles," but I have defined all technicalities in the places where they are first introduced, and these may easily be referred to by means of the Index.

Among the principal additions made to the present edition of the "Elements," exclusive of the incorporation of numerous topics formerly comprised in the Fourth Book of the "Principles," I may call attention to the following: — In the first volume, facts illustrative of the theory of Denudation — Parallel Roads and Terraces — the Boulder formation and erratics — the former extension of Alpine glaciers — methods of classifying the tertiary strata. In the second volume, a description of inland chalk cliffs and needles in Normandy — fossil footsteps, and the discovery of the Labyrinthodon — erect position of fossil trees in the Coal — rocks and fossils of the Old Red Sandstone or Devonian formation — fossils of the Silurian rocks — Tabular view of fossiliferous

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EXPLANATION

OF

THE FRONTISPIECE.

In this plate an ideal representation is given of a deep section of the earth's crust. The masses A, B, C, and D, represent each of them rocks belonging to the four distinct classes; and the reader will perceive what position they may be supposed to occupy relatively to each other when in the course of simultaneous production. Thus, while the aqueous deposits A, which are expressed by the yellow colour, have been accumulating in successive strata at the bottom of the sea, the volcanic cone B has been piled up during a long series of eruptions, and the other igneous rocks coloured purple have also ascended from below in a fluid state. Some of these last have been poured forth into the sea, and there mingled with aqueous sediment. On the left side of the plate a sheet of lava is represented reposing upon the yellow strata A, and covered by other parts of the same sedimentary deposit. This lava was the produce of a submarine eruption, and the horizontal layers of fragments above and below it are volcanic tuffs and conglomerates (see Chap. 27.) On pursuing downwards either the small dikes or large masses of volcanic rock, we find them pass gradually into plutonic formations (or granites) D, which are coloured red, and which underlie all the rest. The different tints of colour express two granites, one newer than the other, but belonging, like the upper and lower strata of A, to the same geological period. These plutonic rocks are seen to be in contact with a zone of contemporaneous metamorphic strata, C, coloured blue, which they penetrate in numerous veins. The formations, C, originated as fossiliferous strata of the periods *d*, *e*, *f*, *g*, *h*, *i*,

but have acquired a new structure during the accumulation of the strata A; and belong therefore to the latter period, or A, if we regard them solely in the light of metamorphic rocks; for during the deposition of A they assumed a crystalline form, and were thus regenerated. This section, therefore, may assist the reader in understanding the doctrine that hypogene strata, such as C, may be formed at a considerable depth from the surface, while the incumbent masses *d*, *e*, *f*, *g*, *h*, *i*, still remain fossiliferous, and in great part unaltered.

In that part of the plate which is uncoloured a more ancient series of mineral masses are seen, belonging also to the four great divisions of rocks. The strata from *a* to *i* represent as many distinct aqueous formations, which have originated at different periods, and are each distinguished by their peculiar fossils. The mass *v v* is of volcanic origin, and was formed when the strata *g* were in the course of deposition. The strata *m* are metamorphic formations, which assumed a crystalline texture before any of the strata C were so altered as to belong to the hypogene class. The rocks 1, 2, are plutonic of different dates, but more ancient than D, D.

The theoretical views elucidated in this Frontispiece are enlarged upon more fully in Vol. I. p. 208., and Vol. II. p. 426.

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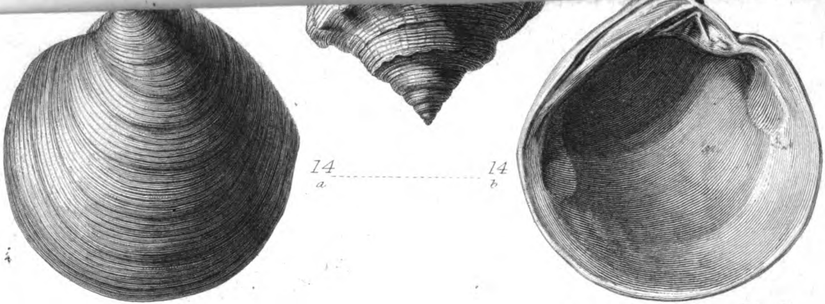

P. Cudart del. T. Bradley sc.

1.2 *Turbo rugosus.* Lin. _ 3.4. *Trochus magus.* Lin. _ 5. *Solarium variegatum.* Lam.[k]
6. *Tornatella fasciata.* Lam.[k] _ 7. *Pleurotoma vulpecula.* Broc. _ 8. *Fusus crispus.* Bors.
9. *Buccinum prismaticum.* Bors. _ 10. *Pleurotoma rotata.* Broc. _ 11. *Buccinum semi-striatum* Broc. _ 12. *Mitra plicatula* Broc. _ 13. *Cassidaria echinophora* Lam.[k] _ 14. *Cytherea exoleta.* Lam.[k] var.

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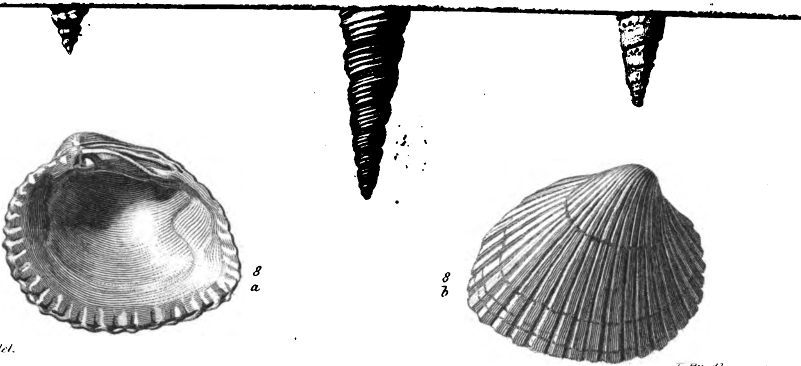
MAP
of Part of
SICILY
14 30'
15
38
30'
37
Capo Milazzo
Milazzo
Capo Calva
Patti
St. Lucia
VAL DI DEMONE
Mojo
Randazzo
Mt. Etna
Calatabiano
R. Simeto
Traino
R. Salso
Aderno
Aci Castello
Trezza
Cyclopian Is.
astrogiovanni
R. Dittaino
Paterno
Misterbianco
CATANIA
Plain of Catania
R. Simeto
R. Giaretta
R. Gurna Longa
Piazza
Palagonia
L. Biveri
Militello
Villasmundo
C. St. Croce
Lentini
Augusta
Caltagirone
Grammichele
Melilli
Vizzini
Sortino
VAL DI NOTO
Pentalica
SYRACUSE
nuova
Floridia
R. Dirillo
Chiaramonte
Vittoria
Ragusa
Noto
R. Ragusa
Modica
Spaccaforno
Pachino
C. Passero
Pt. delle Correnti
1 Volcanic
2 Newer Pliocene
3 Newer Pliocene Alternating with Volcanic
4 Secondary
5 Hypogene
14 30'
15

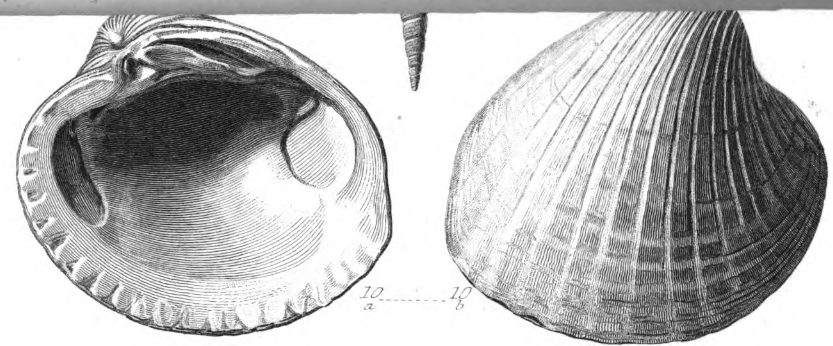


P. Oudart. del.

T. Bradley sculp.

1. *Voluta rarispina*, Lamk. – 2. *Mitra Dufrenei*, Bast. – 3. *Pleurotoma denticula*, Bast.
4. *Nerita Plutonis*, Brong. – 5. *Turritella Proto*, Bast. – 6 *Fasciolaria turbinelloides*, Desh.
7. *Pleurotoma tuberculosa*, Bast. – 8. a. b. *Cardita Ajar*, Brug.

London Published by John Murray 1832.



P. Coulart, del.

T. Bradley, sc.

1. *Voluta costaria*. Lam^k — 2. *Pleurotoma clavicularis* — 3. *Cassidaria carinata*. Lam^k
4. *Nerita tricarinata*. Lam^k — 5. *Calyptræa trochiformis*. Lam^k — 6. *Turritella imbricataria*. Lam^k — 7. *Voluta digitalina*. Lam^k — 8. *Natica epiglottina* Lam^k — 9. *Solarium canaliculatum*. Lam^k — 10. *Cardita planicosta* Desh.

London, Published by John Murray, 1832.



15
13

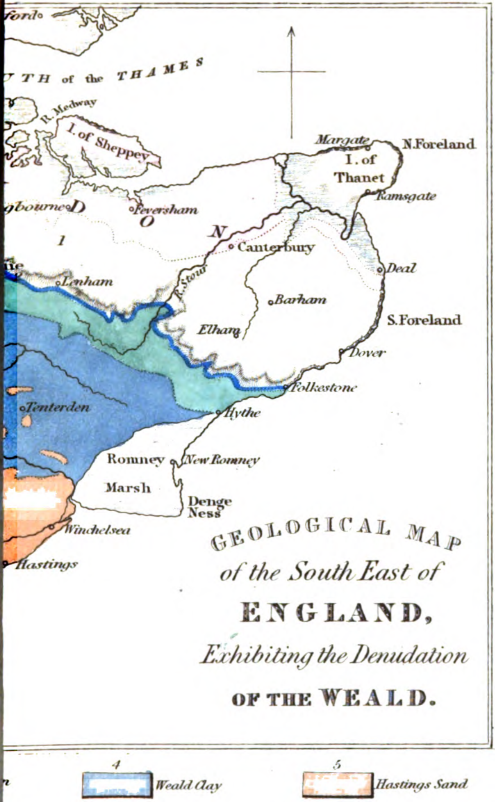
MICROSCOPIC FOSSIL SHELLS. EOCENE TERTIARY PERIOD.

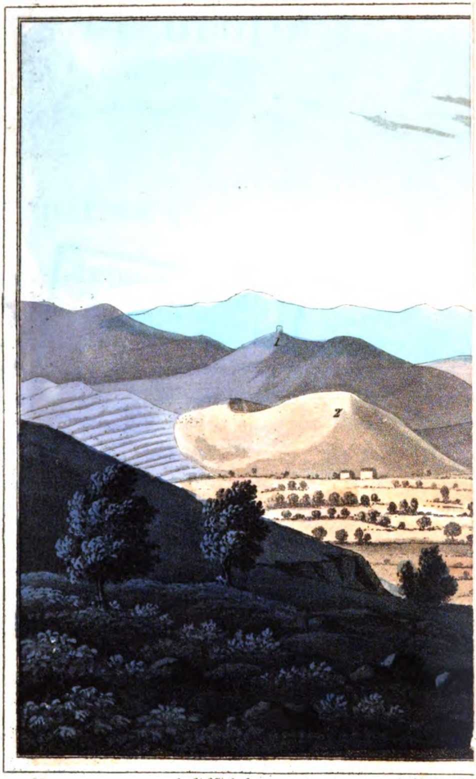
PARIS BASIN

1. 2. 3. 4. _Triloculina inflata. Desh. _5. 6. 7. 8. Quinqueloculina striata. Desh.
9. 10. 11. Calcarina rarispina. Desh. _ 12. 13. 14. Clavulina corrugata. Desh.
15. 16. 17. 18. Spirolina stenostoma. Desh.

London, Published by John Murray Decr 1831.

Plate 6.


GEOLOGICAL MAP
of the South East of
ENGLAND,
Exhibiting the Denudation
OF THE WEALD.
TH of the THAMES
R. Medway
I. of Sheppey
Margate
N.Foreland
I. of Thanet
Ramsgate
Feversham
D
O
N
Canterbury
R. Stour
Lenham
Deal
Barham
Elham
S.Foreland
Dover
Folkestone
Tenterden
Hythe
Romney Marsh
New Romney
Denge Ness
Winchelsea
Hastings
4
Weald Clay
5
Hastings Sand



1, St Michel. 2, Monte Oli

View of the

1 Primary and secondary rocks of Pyrenees.

2

ELEMENTS OF GEOLOGY.

CHAPTER I.

ON THE DIFFERENT CLASSES OF ROCKS.

Geology defined — Successive formation of the earth's crust — Classification of rocks according to their origin and age — Aqueous rocks — Their stratification and imbedded fossils — Volcanic rocks, with and without cones and craters — Plutonic rocks, and their relation to the volcanic — Metamorphic rocks and their probable origin — The term primitive, why erroneously applied to the crystalline formations — Leading division of the work.

Of what materials is the earth composed, and in what manner are these materials arranged? These are the inquiries with which Geology is occupied, a science which derives its name from the Greek γῆ, *ge*, the earth, and λογος, *logos*, a discourse. Such investigations appear, at first sight, to relate exclusively to the mineral kingdom, and to the various rocks, soils, and metals, which occur upon the surface of the earth, or at

various depths beneath it. But, in pursuing these researches, we soon find ourselves led on to consider the successive changes which have taken place in the former state of the earth's surface and interior, and the causes which have given rise to these changes; and, what is still more singular and unexpected, we soon become engaged in researches into the history of the animate creation, or of the various tribes of animals and plants which have, at different periods of the past, inhabited the globe.

All are aware that the solid parts of the earth consist of distinct substances, such as clay, chalk, sand, limestone, coal, slate, granite, and the like; but previously to observation it is commonly imagined that all these had remained from the first in the state in which we now see them,—that they were created in their present form, and in their present position. Geologists have come to a different conclusion. They have discovered proofs that the external parts of the earth were not all produced in the beginning of things, in the state in which we now behold them, nor in an instant of time. On the contrary, they have acquired their actual configuration and condition gradually, under a great variety of circumstances, and at successive periods, during each of which distinct races of living beings have flourished on the land and in the waters, the remains of

these creatures still lying buried in the crust of the earth.

By the "earth's crust," is meant that small portion of the exterior of our planet which is accessible to human observation, or on which we are enabled to reason by observations made at or near the surface. These reasonings may extend to a depth of several miles, perhaps ten miles; and even then it may be said, that such a thickness is no more than $\frac{1}{400}$ part of the distance from the surface to the centre. The remark is just; but although the dimensions of such a crust are, in truth, insignificant when compared to the entire globe, yet they are vast and of magnificent extent in relation to man, and to the organic beings which people our globe. Referring to this standard of magnitude, the geologist may admire the ample limits of his domain, and admit, at the same time, that not only the exterior of the planet, but the entire earth, is but an atom in the midst of the countless worlds surveyed by the astronomer.

Now the materials of this crust are not thrown together confusedly; but distinct mineral masses, called rocks, are found to occupy definite spaces, and to exhibit a certain order of arrangement. The term *rock* is applied indifferently by geologists to all these substances, whether they be soft or stony, for clay and sand are included in the

term, and some have even brought peat under this denomination. Our older writers endeavoured to avoid offering such violence to our language, by speaking of the component materials of the earth as consisting of rocks and *soils*. But there is often so insensible a passage from a soft and incoherent state to that of stone, that geologists of all countries have found it indispensable to have one technical term to include both, and in this sense we find *roche* applied in French, *rocca* in Italian, and *felsart* in German. The beginner, however, must constantly bear in mind, that the term rock by no means implies that a mineral mass is in an indurated or stony condition.

The most natural and convenient mode of classifying the various rocks which compose the earth's crust, is to refer, in the first place, to their origin, and in the second to their relative age. I shall therefore begin by endeavouring briefly to explain to the student how all rocks may be divided into four great classes by reference to their different origin, or, in other words, by reference to the different circumstances and causes by which they have been produced.

The first two divisions, which will at once be understood as natural, are the aqueous and volcanic, or the products of watery and those of igneous action at or near the surface.

Aqueous rocks.—The aqueous rocks, sometimes

called the sedimentary, or fossiliferous, cover a larger part of the earth's surface than any others. These rocks are *stratified*, or divided into distinct layers, or strata. The term *stratum* means simply a bed, or any thing spread out or *strewed* over a given surface; and we infer that these strata have been generally spread out by the action of water, from what we daily see taking place near the mouths of rivers, or on the land during temporary inundations. For, whenever a running stream, charged with mud or sand, has its velocity checked, as when it enters a lake or sea, or overflows a plain, the sediment, previously held in suspension by the motion of the water, sinks, by its own gravity, to the bottom. In this manner layers of mud and sand are thrown down one upon another.

If we drain a lake which has been fed by a small stream, we frequently find at the bottom a series of deposits, disposed with considerable regularity, one above the other; the uppermost, perhaps, may be a stratum of peat, next below a more dense and solid variety of the same material; still lower a bed of shell-marl, alternating with peat or sand, and then other beds of marl, divided by layers of clay. Now, if a second pit be sunk through the same continuous lacustrine *formation*, at some distance from the first, nearly the same series of beds is commonly met with, yet with

slight variations; some, for example, of the layers of sand, clay, or marl, may be wanting, one or more of them having thinned out and given place to others, or sometimes one of the masses first examined is observed to increase in thickness to the exclusion of other beds.

The term "*formation*," which I have used in the above explanation, expresses in geology any assemblage of rocks which have some character in common, whether of origin, age, or composition. Thus we speak of stratified and unstratified, freshwater and marine, aqueous and volcanic, ancient and modern, metalliferous and non-metalliferous formations.

In the estuaries of large rivers, such as the Ganges and the Mississippi, we may observe, at low water, phenomena analogous to those of the drained lakes above mentioned, but on a grander scale, and extending over areas several hundred miles in length and breadth. When the periodical inundations subside, the river hollows out a channel to the depth of many yards through horizontal beds of clay and sand, the ends of which are seen exposed in perpendicular cliffs. These beds vary in colour, and are occasionally characterized by containing drift-wood or shells. The shells may belong to species peculiar to the river, but are sometimes those of marine testacea, washed into the mouth of the estuary during storms.

The annual floods of the Nile in Egypt are well known, and the fertile deposits of mud which they leave on the plains. This mud is *stratified*, the thin layer thrown down in one season differing slightly in colour from that of a previous year, and being separable from it, as has been observed in excavations at Cairo, and other places.*

When beds of sand, clay, and marl, containing shells and vegetable matter, are found arranged in the same manner in the interior of the earth, we ascribe to them a similar origin; and the more we examine their characters in minute detail, the more exact do we find the resemblance. Thus, for example, at various heights and depths in the earth, and often far from seas, lakes, and rivers, we meet with layers of rounded pebbles composed of different rocks mingled together. They are like the shingle of a sea-beach, or pebbles formed in the beds of torrents and rivers, which are carried down into the ocean wherever these descend from high grounds bordering a coast. There the gravel is spread out by the waves and currents over a considerable space; but during seasons of drought the torrents and rivers are nearly dry, and have only power to convey fine sand or mud into the sea. Hence, alternate layers of gravel and fine sediment accumulate under water, and

* See Principles of Geology, by the Author, Index, "Nile," "Rivers," &c.

such alternations are found by geologists in the interior of every continent.*

If a stratified arrangement, and the rounded forms of pebbles, are alone sufficient to lead us to the conclusion that certain rocks originated under water, this opinion is farther confirmed by the distinct and independent evidence of *fossils*, so abundantly included in the earth's crust. By a *fossil* is meant any body, or the traces of the existence of any body, whether animal or vegetable, which has been buried in the earth by natural causes. Now the remains of animals, especially of aquatic species, are found almost everywhere imbedded in stratified rocks, and sometimes, in the case of limestone, they are in such abundance as to constitute the entire mass of the rock itself. Shells and corals are the most frequent, and with them are often associated the bones and teeth of fishes, fragments of wood, impressions of leaves, and other organic substances. Fossil shells of forms, such as now abound in the sea, are met with far inland, both near the surface and at great depths below it. They occur at all heights above the level of the ocean, having been observed at an elevation of from 8000 to 9000 feet in the Alps and Pyrenees, of more than 13,000 feet in the Andes, and above 16,000 feet in the Himalayas.†

* See p. 38.

† See Geograph. Journ. vol. iv. p. 64.

These shells belong mostly to marine testacea, but in some places exclusively to forms characteristic of lakes and rivers. Hence it is concluded that some ancient strata were deposited at the bottom of the sea, and others in lakes and estuaries.

When geology was first cultivated, it was a general belief, that these marine shells and other fossils were the effects and proofs of the general deluge; but all who have carefully investigated the phenomena have long rejected this doctrine. A transient flood might be supposed to leave behind it, here and there upon the surface, scattered heaps of mud, sand, and shingle, with shells confusedly intermixed; but the strata containing fossils are not superficial deposits, and do not cover the earth, but constitute the entire mass of mountains. Nor are the fossils mingled without reference to the habits of the creatures, certain genera or species being often found in groups unassociated with any others.

It has been also the favourite notion of some modern writers, who are aware that fossil bodies cannot all be referred to the deluge, that they, and the strata in which they are entombed, may have been deposited in the bed of the ocean during the period which intervened between the creation of man and the deluge. They imagine that the antediluvian bed of the ocean, after having been the receptacle of many stratified

deposits, became converted, at the time of the flood, into the lands which we inhabit, and that the ancient continents were at the same time submerged, and became the bed of the present sea. This hypothesis, although preferable to the diluvial theory, since it admits that all fossiliferous strata were successively thrown down from water, is yet wholly inadequate to explain the repeated revolutions which the earth has undergone, and the signs which the existing continents exhibit, in most regions, of having emerged from the ocean at an era far more remote than four thousand years from the present time. Ample proofs of these reiterated revolutions will be given in the sequel, and it will be seen that many distinct sets of sedimentary strata, each several hundreds or thousands of feet thick, are piled one upon the other in the earth's crust, each containing peculiar fossil animals and plants, which are distinguishable with few exceptions from species now living. The mass of some of these strata consists almost entirely of corals, others are made up of shells, others of plants turned into coal, while some are without fossils. In one set of strata the species of fossils are marine, in another, placed immediately above or below, they as clearly prove that the deposit was formed in a brackish estuary or lake. When the student has more fully examined into these appearances, he will become convinced that

the time required for the origin of the actual co-
tinents must have been far greater than that whi
is conceded by the theory above alluded to; an
likewise that no one universal and sudden con-
version of sea into land will account for geological
appearances.

We have now pointed out one great class of rocks, which, however they may vary in mineral composition, colour, grain, or other characters, external and internal, may nevertheless be grouped together as having a common origin. They have all been formed under water, in the same manner as modern accumulations of sand, mud, shingle, banks of shells, reefs of coral, and the like, and are all characterized by stratification or fossils, or by both.

Volcanic rocks.—The division of rocks which we may next consider are the volcanic, or those which have been produced at or near the surface whether in ancient or modern times, not by water, but by the action of fire or subterranean heat. These rocks are for the most part unstratified, and are devoid of fossils. They are more partially distributed than aqueous formations, at least in respect to horizontal extension. Among those parts of Europe where they exhibit characters not to be mistaken, I may mention not only Sicily and the country round Naples, but Auvergne, Velay, and Vivarais, now the depart-

ents of Puy de Dome, Haute Loire, and Ardèche, towards the centre and south of France, in which are several hundred conical hills having the forms of modern volcanos, with craters more or less perfect on many of their summits. These cones are composed moreover of lava, sand, and ashes, similar to those of active volcanos. Streams of lava may sometimes be traced from the cones into the adjoining valleys, where they have choked up the ancient channels of rivers with solid rock, in the same manner as some modern flows of lava in Iceland have been known to do, the rivers either flowing beneath or cutting out a narrow passage on one side of the lava. Although none of these French volcanos have been in activity within the period of history or tradition, their forms are often very perfect. Some, however, have been compared to the mere skeletons of volcanos, the rains and torrents having washed their sides, and removed all the loose sand and scoriæ, leaving only the harder and more solid materials. By this erosion, and by earthquakes, their internal structure has occasionally been laid open to view, in fissures and ravines; and we then behold not only many successive beds and masses of porous lava, sand, and scoriæ, but also perpendicular walls, or *dikes*, as they are called, of volcanic rock, butting through the other materials. Such dikes are also observed in the structure of Vesuvius,

Etna, and other active volcanos. They have been formed by the pouring of melted matter, whether from above or below, into open fissures, and they commonly traverse deposits of *volcanic tuff*, a substance produced by the showering down from the air, or incumbent waters, of sand and cinders, first shot up from the interior of the earth by the explosions of volcanic gases.

Besides the parts of France above alluded to, there are other countries, as the north of Spain, the south of Sicily, the Tuscan territory of Italy, the lower Rhenish provinces, and Hungary, where spent volcanos may be seen, still preserving in many cases a conical form, and having craters and often lava-streams connected with them.

There are also other rocks in England, Scotland, Ireland, and almost every country in Europe, which we infer to be of igneous origin, although they do not form hills with cones and craters. Thus, for example, we feel assured that the rock of Staffa, and that of the Giants' Causeway, called basalt, is volcanic, because it agrees in its columnar structure and mineral composition with streams of lava which we know to have flowed from the craters of volcanos. We find also similar basaltic and other igneous rocks associated with beds of *tuff* in various parts of the British Isles, and forming *dikes*, such as have been spoken of; and some of the strata through which these dikes cut

are occasionally altered at the point of contact, as if they had been exposed to the intense heat of melted matter.

The absence of cones and craters, and long narrow streams of superficial lava, in England and many other countries, is principally to be attributed to the eruptions having been submarine, just as a considerable proportion of volcanos in our own times burst out beneath the sea. But this question must be enlarged upon more fully in the chapters on Igneous Rocks, in which it will also be shown, that as different sedimentary formations, containing each their characteristic fossils, have been deposited at successive periods, so also volcanic sand and scoriæ have been thrown out, and lavas have flowed over the land or bed of the sea, at many different epochs, or have been injected into fissures; so that the igneous as well as the aqueous rocks may be classed as a chronological series of monuments, throwing light on a succession of events in the history of the earth.

Plutonic rocks (Granite, &c.). — We have now pointed out the existence of two distinct orders of mineral masses, the aqueous and the volcanic: but if we examine a large portion of a continent, especially if it contain within it a lofty mountain range, we rarely fail to discover two other classes of rocks, very distinct from either of those above alluded to, and which we can neither assimilate

to deposits such as are now accumulated in lakes or seas, nor to those generated by ordinary volcanic action. The members of both these divisions of rocks agree in being highly crystalline and destitute of organic remains. The rocks of one division have been called plutonic, comprehending all the granites and certain porphyries, which are nearly allied in some of their characters to volcanic formations. The members of the other class are stratified and often slaty, and have been called by some the *crystalline schists*, in which group are included gneiss, micaceous-schist (or mica-slate), hornblende-schist, statuary marble, the finer kinds of roofing slate, and other rocks afterwards to be described.

As it is admitted that nothing strictly analogous to these crystalline productions can now be seen in the progress of formation on the earth's surface, it will naturally be asked, on what data we can find a place for them in a system of classification founded on the origin of rocks. I cannot, in reply to this question, pretend to give the student, in a few words, an intelligible account of the long chain of facts and reasonings by which geologists have been led to infer the analogy of the rocks in question to others now in progress at the surface. The result, however, may be briefly stated. All the various kinds of granite, which constitute the plutonic family, are supposed to

be of igneous origin, but to have been formed under enormous pressure, and at considerable depths in the earth. Like the lava of volcanos, they have been melted, and have afterwards cooled and crystallized, but with extreme slowness, and under conditions very different from those of bodies cooling in the open air. Hence they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases gives rise in ordinary lava.

Although granite has often pierced through other strata, it has rarely, if ever, been observed to rest upon them, as if it had overflowed. But as this is continually the case with the volcanic rocks, they have been styled from this peculiarity, "overlying" by Dr. MacCulloch; and Mr. Necker has proposed the term "underlying" for the granites, to designate the opposite mode in which they almost invariably present themselves.

Metamorphic, or stratified crystalline rocks. — The fourth and last great division of rocks are the crystalline strata and slates, or schists, called gneiss, mica-schist, clay-slate, chlorite-schist, marble, and the like, the origin of which is more

doubtful than that of the other three classes. They contain no pebbles or sand or scoriæ, or angular pieces of imbedded stone, and no traces of organic bodies, and they are often as crystalline as granite, yet are divided into beds, corresponding in form and arrangement to those of sedimentary formations, and are therefore said to be stratified. The beds sometimes consist of an alternation of substances varying in colour, composition, and thickness, precisely as we see in stratified fossiliferous deposits. According to the Huttonian theory, which I adopt as most probable, and which will be afterwards more fully explained, the materials of these strata were originally deposited from water in the usual form of sediment, but they were subsequently so altered by subterranean heat, as to assume a new texture. It is demonstrable, in some cases at least, that such a complete conversion has actually taken place, fossiliferous strata having exchanged an earthy for a highly crystalline texture for a distance of a quarter of a mile from their contact with granite. In some cases, dark limestones, replete with shells and corals, have been turned into white statuary marble, and hard clays into slates called mica-schist and hornblende-schist, all signs of organic bodies having been obliterated.

Although we are in a great degree ignorant of the precise nature of the influence exerted in these

cases, yet it evidently bears some analogy to that which volcanic heat and gases are known to produce; and the action may be conveniently called plutonic, because it appears to have been developed in those regions where plutonic rocks are generated, and under similar circumstances of pressure and depth in the earth. Whether electricity or any other causes have co-operated with heat, may be matter of speculation, but the plutonic influence has sometimes pervaded entire mountain masses of strata.

In accordance with the hypothesis above alluded to, I proposed in the first edition of the Principles of Geology (1833), the term "Metamorphic" for the altered strata, a term derived from *μετα*, meta, *trans*, and *μορφη*, morphe, *forma*.

Hence there are four great classes of rocks considered in reference to their origin,—the aqueous, the volcanic, the plutonic, and the metamorphic. In the course of this work it will be shewn, that portions of each of these four distinct classes have originated at many successive periods. They have all been produced contemporaneously, and may even now be in the progress of formation. It is not true, as was formerly supposed, that all granite, together with the crystalline or metamorphic strata, were first formed, and therefore entitled to be called "primitive," and that the

aqueous and volcanic rocks were afterwards superimposed, and should, therefore, rank as secondary in the order of time. This idea was adopted in the infancy of the science, when all formations, whether stratified or unstratified, earthy or crystalline, with or without fossils, were alike regarded as of aqueous origin. At that period it was naturally argued, that the foundation must be older than the superstructure; but it was afterwards discovered, that this opinion was by no means in every instance a legitimate deduction from facts; for the inferior parts of the earth's crust have often been modified, and even entirely changed by the influence of volcanic and other subterranean causes, while superimposed formations have not been in the slightest degree altered. In other words, the destroying and renovating processes have given birth to new rocks below, while those above, whether crystalline or fossiliferous, have remained in their ancient condition. Even in cities, such as Venice and Amsterdam, it cannot be laid down as universally true, that the upper parts of each edifice, whether of brick or marble, are more modern than the foundations on which they rest, for these often consist of wooden piles, which may have rotted and been replaced one after the other, without the least injury to the buildings above; meanwhile, these may have required scarcely any

repair, and may have been constantly inhabited. So is it with the habitable surface of our globe, and with large masses of rock immediately below it: they may continue the same for ages, while subjacent materials, at a still greater depth, are passing from a solid to a fluid state, acquiring a new texture, and afterwards becoming re-consolidated.

As all the crystalline rocks may, in some respects, be viewed as belonging to one great family, whether they be stratified or unstratified, plutonic or metamorphic, it will often be convenient to speak of them by one common name. It being now ascertained, as above stated, that they are of very different ages, sometimes newer than the strata called secondary, the term primary, which was formerly used for the whole, must be abandoned, as it would imply a manifest contradiction. It is indispensable, therefore, to find a new name, one which must not be of chronological import, and must express, on the one hand, some peculiarity equally attributable to granite and gneiss (to the plutonic as well as the *altered* rocks), and, on the other, must have reference to characters in which those rocks differ, both from the volcanic and from the *unaltered* sedimentary strata. I proposed in the Principles of Geology (first edition, vol. iii.), the term "hypogene" for this purpose, derived from ὑπο, *under*, and γινομαι, *to be born;*

a word implying the theory that granite, gneiss, and the other crystalline formations are alike *nether-formed* rocks, or rocks which have not assumed their present form and structure at the surface.

From what has now been said, the reader will understand that each of the four great classes of rocks may be studied under two distinct points of view: first, they may be studied simply as mineral masses deriving their origin from particular causes, and having a certain composition, form, and position in the earth's crust, or other characters both positive and negative, such as the presence or absence of organic remains. In the second place, the rocks of each class may be viewed as a grand chronological series of monuments, attesting a succession of events in the former history of the globe and its living inhabitants.

I shall accordingly proceed to treat of each family of rocks; first, in reference to those characters which are not chronological, and then in particular relation to the several periods when they were formed.

CHAPTER II.

AQUEOUS ROCKS — THEIR COMPOSITION AND FORMS OF STRATIFICATION.

Mineral composition of strata — Arenaceous rocks — Argillaceous — Calcareous — Gypsum — Forms of stratification — Original horizontality — thinning out — Diagonal arrangement — Ripple mark.

First, then, in pursuance of the arrangement explained in the last chapter, we have to examine the aqueous or sedimentary rocks, which are for the most part distinctly stratified, and contain fossils. We are first to consider them with reference to their mineral composition, external appearance, position, mode of origin, and other characters which belong to them as aqueous formations, independently of their age, or the various geological periods when they may have originated.

I have already given an outline of the data which led to the belief that the stratified and fossiliferous rocks were originally deposited under water; but, before entering into a more detailed investigation, it will be desirable to say something of the ordinary materials of which such strata are composed. These may be said to belong

principally to three divisions, the arenaceous, the argillaceous, and the calcareous, which are formed respectively of sand, clay, and carbonate of lime. Of these, the arenaceous, or sandy masses, are chiefly made up of siliceous or flinty grains; the argillaceous, or clayey, of a mixture of siliceous matter, with a certain proportion, about a fourth in weight, of aluminous earth; and, lastly, the calcareous rocks or limestones consist of carbonic acid and lime.

Arenaceous or siliceous rocks.—To speak first of the sandy division: beds of loose sand are frequently met with, of which the grains consist entirely of silex, which term comprehends all purely siliceous minerals, as quartz and common flint. Quartz is silex in its purest form; flint usually contains some admixture of alumine and oxide of iron. The siliceous grains in sand are usually rounded, as if by the action of running water. Sandstone is an aggregate of such grains, which often cohere together without any visible cement, but more commonly are bound together by a slight quantity of siliceous or calcareous matter, or by iron or clay.

Pure siliceous rocks may be known by not effervescing when a drop of vinegar or other acid is applied to them, or by the grains not being readily scratched or broken by ordinary pressure. In nature there is every intermediate gradation,

from perfectly loose sand, to the hardest sandstone. In *micaceous sandstones* mica is very abundant; and the thin silvery plates into which that mineral divides, are often arranged in layers parallel to the planes of stratification, giving a slaty or laminated texture to the rock.

When sandstone is coarse-grained, it is usually called *grit.* If the grains are rounded, and large enough to be called pebbles, it becomes a *conglomerate*, or *pudding-stone*, which may consist of pieces of one or of many different kinds of rock. A conglomerate, therefore, is simply gravel bound together by a cement.

Argillaceous rocks.—Clay, strictly speaking, is a mixture of silex or flint with a large proportion, usually about one fourth, of the substance called alumine, or argil; but, in common language, any earth which possesses sufficient ductility, when kneaded up with water, to be fashioned like paste by the hand, or by the potter's lathe, is called a *clay;* and such clays vary greatly in their composition, and are, in general, nothing more than mud derived from the decomposition or wearing down of various rocks. The purest clay found in nature is porcelain clay, or kaolin, which results from the decomposition of a rock composed of felspar and quartz, and it is almost always mixed with quartz.* *Shale* has also the property, like

* The kaolin of China consists of 71·15 parts of silex,

clay, of becoming plastic in water: it is a more solid form of clay, having been probably condensed by pressure. It usually divides into irregular laminæ.

One general character of all argillaceous rocks is to give out a peculiar or earthy odour when breathed upon, which is a test of the presence of alumine, although it does not belong to pure alumine, but, apparently, to the combination of that substance with oxide of iron.*

Calcareous rocks.—This division comprehends those rocks which, like chalk, are composed chiefly of lime and carbonic acid. Shells and corals are also formed of the same elements, with the addition of animal matter. To obtain pure lime it is necessary to calcine these calcareous substances, that is to say, to expose them to heat of sufficient intensity to drive off the carbonic acid, and other volatile matter, without vitrifying or melting the lime itself. White chalk is often pure carbonate of lime; and this rock, although usually in a soft and earthy state, is sometimes sufficiently solid to be used for building, and even passes into a

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15·86 of alumine, 1·92 of lime, and 6·73 of water (W. Phillips, Mineralogy, p. 33.); but other porcelain clays differ materially, that of Cornwall being composed, according to Boase, of nearly equal parts of silica and alumine, with 1 per cent. of magnesia. (Phil. Mag. vol. x. 1837.)

* See W. Phillips's Mineralogy, "Alumine."

compact stone, or a stone of which the separate parts are so minute as not to be distinguishable from each other by the naked eye.

Many limestones are made up entirely of minute fragments of shells and coral, or of calcareous sand cemented together. These last might be called "calcareous sandstones;" but that term is more properly applied to a rock in which the grains are partly calcareous and partly siliceous, or to quartzose sandstones, having a cement of carbonate of lime.

The variety of limestone called "oolite" is composed of numerous small egg-like grains, resembling the roe of a fish, each of which has usually a small fragment of sand as a nucleus, around which concentric layers of calcareous matter have accumulated.

Any limestone which is sufficiently hard to take a fine polish is called *marble.* Many of these are fossiliferous; but statuary marble, which is also called saccharine limestone, as having a texture resembling that of loaf-sugar, is devoid of fossils, and is in many cases a member of the metamorphic series.

Siliceous limestone is an intimate mixture of carbonate of lime and flint, and is harder in proportion as the flinty matter predominates.

The presence of carbonate of lime in a rock may be ascertained by applying to the surface a

small drop of diluted sulphuric, nitric, or muriatic acids, or vinegar; for the lime, having a stronger chemical affinity for any one of these acids than for the carbonic, unites itself immediately with them to form new compounds, thereby becoming a sulphate, nitrate, or muriate of lime. The carbonic acid, when thus liberated from its union with the lime, escapes in a gaseous form, and froths up or effervesces as it makes its way in small bubbles through the drop of liquid. This effervescence is brisk or feeble in proportion as the limestone is pure or impure, or, in other words, according to the quantity of foreign matter mixed with the carbonate of lime. Without the aid of this test, the most experienced eye cannot always detect the presence of lime in rocks.

The above-mentioned three classes of rocks, the arenaceous, argillaceous, and calcareous, pass continually into each other, and rarely occur in a perfectly separate and pure form. Thus it is an exception to the general rule to meet with a limestone as pure as ordinary white chalk, or with clay as aluminous as that used in Cornwall for porcelain, or with sand so entirely composed of siliceous grains as the white sand of Alum Bay in the Isle of Wight, or sandstone so pure as the grit of Fontainebleau, used for pavement in France. More commonly we find sand and clay, or clay and marl, intermixed in the same mass. When the

sand and clay are each in considerable quantity, the mixture is called *loam*. If there is much calcareous matter in clay it is called *marl;* but this term has unfortunately been used so vaguely, as often to be very ambiguous. It has been applied to substances in which there is no lime; as, to that red loam usually called red marl in certain parts of England. Agriculturists were in the habit of calling any soil a marl, which, like true marl, fell to pieces readily on exposure to the air. Hence arose the confusion of using this name for soils which, consisting of loam, were easily worked by the plough, though devoid of lime.

Marl slate bears the same relation to marl which shale bears to clay, being a calcareous shale. It is very abundant in some countries, as in the Swiss Alps. Argillaceous or marly limestone is also of common occurrence.

There are few other kinds of rock which enter so largely into the composition of sedimentary strata as to make it necessary to dwell here on their characters. I may, however, mention two others, — magnesian limestone or dolomite, and gypsum. *Magnesian limestone* is composed of carbonate of lime and carbonate of magnesia: the proportion of the latter amounting in some cases to nearly one half. It effervesces much more slowly and feebly with acids than common limestone. In England this rock is generally of a yellowish

colour; but it varies greatly in mineralogical character, passing from an earthy state to a white compact stone of great hardness. *Dolomite*, so common in many parts of Germany and France, is also a variety of magnesian limestone, usually of a granular texture.

Gypsum. — Gypsum is a rock composed of sulphuric acid, lime, and water. It is usually a soft whitish-yellow rock, with a texture resembling that of loaf-sugar, but sometimes it is entirely composed of lenticular crystals. It is insoluble in acids, and does not effervesce like chalk and dolomite, because it does not contain carbonic acid gas, or fixed air, the lime being already combined with sulphuric acid, for which it has a stronger affinity than for any other. Anhydrous gypsum is a rare variety, into which water does not enter as a component part. Gypseous marl is a mixture of gypsum and marl.

Forms of stratification. — A series of strata sometimes consists of one of the above rocks, sometimes of two or more in alternating beds. Thus, in the coal districts of England, for example, we often pass through several beds of sandstone, some of finer, others of coarser grain, some white, others of a dark colour, and below these, layers of shale and sandstone or beds of shale, divisible into leaf-like laminæ, and containing beautiful impressions of plants. Then again we meet with beds of pure

and impure coal, alternating with shales, and underneath the whole, perhaps, are calcareous strata, or beds of limestone, filled with corals and marine shells, each bed distinguishable from another by certain fossils, or by the abundance of particular species of shells or zoophytes.

This alternation of different kinds of rock produces the most distinct stratification; and we often find beds of limestone and marl, conglomerate and sandstone, sand and clay, recurring again and again, in nearly regular order, throughout a series of many hundred strata. The causes which may produce these phenomena are various, and have been fully discussed in my treatise on the modern changes of the earth's surface.* It is there seen that rivers flowing into lakes and seas are charged with sediment, varying in quantity, composition, colour, and grain according to the seasons; the waters are sometimes flooded and rapid, at other periods low and feeble; different tributaries, also, draining peculiar countries and soils, and therefore charged with peculiar sediment, are swollen at distinct periods. It was also shown that the waves of the sea and currents undermine the cliffs during wintry storms, and sweep away the materials into the deep, after which a season of tranquillity succeeds, when nothing but the finest

* Consult Index to Prin. of Geol. "Stratification," "Currents," "Deltas," "Water," &c.

mud is spread by the movements of the ocean over the same submarine area.

It is not the object of the present work to give a description of these operations, repeated as they are, year after year, and century after century; but I may suggest an explanation of the manner in which some micaceous sandstones have originated, those in which we see innumerable thin layers of mica dividing layers of fine quartzose sand. I observed the same arrangement of materials in recent mud deposited in the estuary of La Roche St. Bernard in Brittany, at the mouth of the Loire. The surrounding rocks are of gneiss, which, by its waste, supplies the mud: when this dries at low water, it is found to consist of brown laminated clay, divided by thin seams of mica. The separation of the mica in this case, or in that of micaceous sandstones, may be thus understood. If we take a handful of quartzose sand, mixed with mica, and throw it into a clear running stream, we see the materials immediately sorted by the water, the grains of quartz falling almost directly to the bottom, while the plates of mica take a much longer time to reach the bottom, and are carried farther down the stream. At the first instant the water is turbid, but immediately after the flat surfaces of the plates of mica are seen alone reflecting a silvery light, and they descend slowly, to form a distinct micaceous lamina. The mica is

the heavier mineral of the two; but it remains longer suspended, owing to its great extent of surface. It is easy, therefore, to conceive how the intermittent action of waves, currents, and tides, may sort the sediment brought down from the waste of a granitic country, and throw down the mica, layer after layer, separately from the mud or sand.

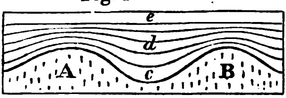
Original horizontality.—It has generally been said that the upper and under surfaces of strata, or the planes of stratification, as they are termed, are parallel. Although this is not strictly true, they make an approach to parallelism, for the same reason that sediment is usually deposited at first in nearly horizontal layers. The reason of this arrangement can by no means be attributed to an original evenness or horizontality in the bed of the sea; for it is ascertained that in those places where no matter has been recently deposited, the bottom of the ocean is often as uneven as that of the dry land, having in like manner its hills, valleys, and ravines. Yet if the sea should sink, or the water be removed near the mouth of a large river where a delta has been forming, we should see extensive plains of mud and sand laid dry, which, to the eye, would appear perfectly level, although, in reality, they would slope gently from the land towards the sea.

This tendency in newly-formed strata to assume a horizontal position arises principally from the

motion of the water, which forces along particles of sand or mud at the bottom, and causes them to settle in hollows or depressions, where they are less exposed to the force of a current than when they are resting on elevated points. The velocity of the current and the motion of the superficial waves diminish from the surface downwards, and are least in those depressions where the water is deepest.

A good illustration of the principle here alluded to may be sometimes seen in the neighbourhood of a volcano, when a section, whether natural or artificial, has laid open to view a succession of various-coloured layers of sand and ashes, which have fallen in showers upon uneven ground. Thus let A, B (Fig. 1.) be two ridges, with an intervening valley. These original inequalities of the surface have been gradually effaced by beds of sand and ashes *c*, *d*, *e*, the surface at *e* being quite level. It will be seen that although the materials of the first layers have accommodated themselves in a great degree to the shape of the ground A B, yet each bed is thickest at the bottom. At first a great many particles would be carried by their own gravity down the steep sides of A and B, and others would afterwards be blown by the wind as they fell off the ridges, and would settle in the hollow, which would thus be-

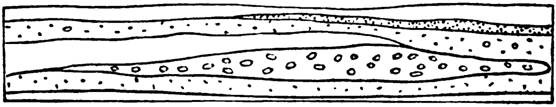
Fig. 1.



come more and more effaced as the strata accumulated from *c* to *e*. This levelling operation may perhaps be rendered more clear to the student by supposing a number of parallel trenches to be dug in a plain of moving sand, like the African desert, in which case the wind would soon cause all signs of these trenches to disappear, and the surface would be as uniform as before. Now, water in motion can exert this levelling power on similar materials more easily than air, for almost all stones lose in water more than a third of the weight which they have in air, the specific gravity of rocks being in general as 2½ when compared to that of water, which is estimated at 1. But the buoyancy of sand or mud would be still greater in the sea, as the density of salt water exceeds that of fresh.

Yet, however uniform and horizontal may be the surface of new deposits in general, there are still many disturbing causes, such as eddies in the water, and currents moving first in one and then in another direction, which frequently cause irregularities. We may sometimes follow a bed of limestone, shale, or sandstone, for a distance of many hundred yards continuously; but we generally find at length that each individual stratum thins

Fig. 2.

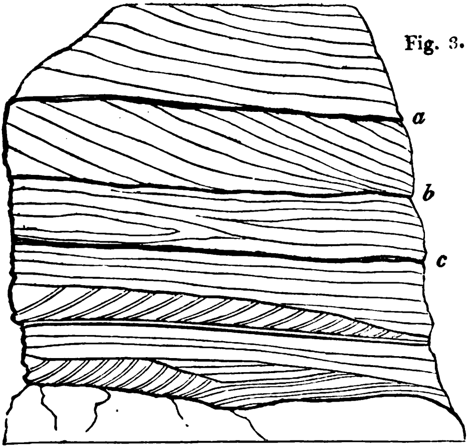


Section of strata of sandstone, grit, and conglomerate.

out, and allows the beds which were previously above and below it to meet. If the materials are coarse, as in grits and conglomerates, the same beds can rarely be traced many yards without varying in size, and often coming to an end abruptly. (See Fig. 2.)

Diagonal Stratification. — There is also another phenomenon of frequent occurrence. We find a series of larger strata, each of which is composed of a number of minor layers placed obliquely to the general planes of stratification. To this diagonal arrangement the name of "false stratification" has been given. Thus in the annexed section (Fig. 3.) we see seven or eight large beds

Fig. 3.

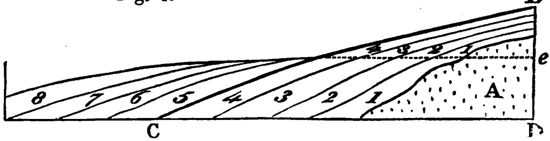


Section of sand at Sandy Hill, near Biggleswade, Bedfordshire. Height twenty feet. (Green-sand formation.)

of loose sand, yellow and brown, and the lines *a*,

b, *c*, mark some of the principal planes of stratification, which are nearly horizontal. But the greater part of the subordinate laminæ do not conform to these planes, but have often a steep slope, the inclination being sometimes towards opposite points of the compass. When the sand is loose and incoherent, as in the case here represented, the deviation from parallelism of the slanting laminæ cannot possibly be accounted for by any re-arrangement of the particles acquired during the consolidation of the rock. In what manner then can such irregularities be due to original deposition? We must suppose that at the bottom of the sea, as well as in the beds of rivers, the motions of waves, currents, and eddies often cause mud, sand, and gravel to be thrown down in heaps on particular spots, instead of being spread out uniformly over a wide area. Sometimes, when banks are thus formed, currents may cut passages through them, just as a river forms its bed. Suppose the bank A (Fig. 4.) to be thus formed with a steep sloping side, and the

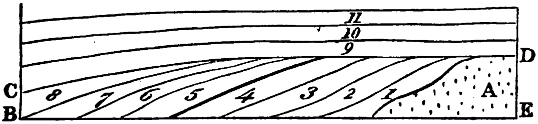
Fig. 4.



water being in a tranquil state, the layer of sediment No. 1. is thrown down upon it, conforming

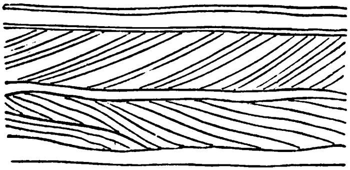
nearly to its surface. Afterwards the other layers, 2, 3, 4, may be deposited in succession, so that the bank B C D is formed. If the current then increases in velocity, it may cut away the upper portion of this mass down to the dotted line *e* (Fig. 4.), and deposit the materials thus removed farther on, so as to form the layers 5, 6, 7, 8. We have now the bank B C D E (Fig. 5.), of

Fig. 5.



which the surface is almost level, and on which the nearly horizontal layers, 9, 10, 11, may then accumulate. It was shown in Fig. 3. that the diagonal layers of successive strata may sometimes have an opposite slope. This is well seen in some cliffs of loose sand on the Suffolk coast. A portion of one of these is represented in Fig. 6., where the

Fig. 6.



Cliff between Mismer and Dunwich.

layers, of which there are about six in the thickness of an inch, are composed of quartzose grains.

This arrangement may have been due to the altered direction of the tides and currents in the same place.

The description above given of the slanting position of the minor layers constituting a single stratum is in certain cases applicable on a much grander scale to masses several hundred feet thick, and many miles in extent. A fine example may be seen at the base of the Maritime Alps near Nice. The mountains here terminate abruptly in the sea, so that a depth of many hundred fathoms is often found within a stone's throw of the beach, and sometimes a depth of 3000 feet within half a mile. But at certain points, strata of sand, marl, or conglomerate, intervene between the shore and the mountains, as in the annexed Fig. (7.), where a vast succession of slanting beds of gravel and sand may be traced

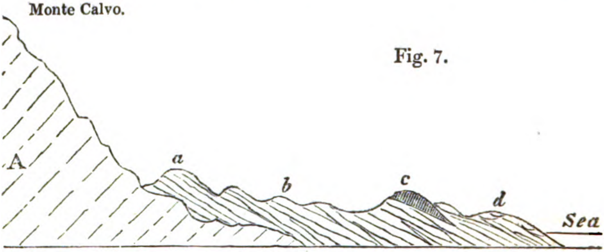


Fig. 7.

Section from Monte Calvo to the sea by the valley of Magnan, near Nice.

A. Dolomite and sandstone. (Green-sand formation ?)
a, *b*, *d*. Beds of gravel and sand.
c. Fine marl and sand of St. Madeleine, with marine shells.

from the sea to Monte Calvo, a distance of no less than 9 miles in a straight line. The dip of these beds is remarkably uniform, being always southward or towards the Mediterranean, at an angle of about 25°. They are exposed to view in nearly vertical precipices, varying from 200 to 600 feet in height, which bound the valley through which the river Magnan flows. Although in a general view, the strata appear to be parallel and uniform, they are nevertheless found, when examined closely, to be wedge-shaped, and to thin out when followed for a few hundred feet or yards, so that we may suppose them to have been thrown down originally upon the side of a steep bank, where a river or alpine torrent discharged itself into a deep and tranquil sea, and formed a delta, which advanced gradually from the base of Monte Calvo to a distance of 9 miles from the original shore. If subsequently this part of the Alps and bed of the sea were raised 700 feet, the coast would acquire its present configuration, the delta would emerge, and a deep channel might then be cut through it by a river.

It is well known that the torrents and streams, which now descend from the alpine declivities to the shore, bring down annually, when the snow melts, vast quantities of shingle and sand, and then, as they subside, fine mud, while in summer they are nearly or entirely dry; so that it may be

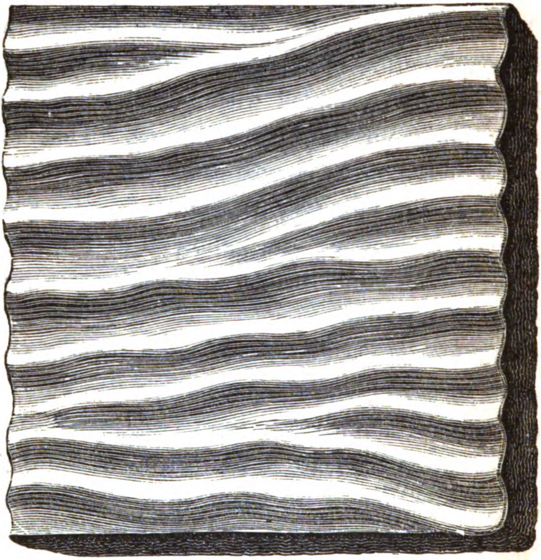
safely assumed, that deposits like those of the valley of the Magnan, consisting of coarse gravel alternating with fine sediment, are still in progress at many points, as for instance, at the mouth of the Var. They must advance upon the Mediterranean in the form of great shoals terminating in a steep talus; such being the original mode of accumulation of all coarse materials conveyed into deep water, especially where they are composed, in great part, of pebbles, which cannot be transported to indefinite distances by currents of moderate velocity. By inattention to facts and inferences of this kind, a very exaggerated estimate has sometimes been made of the supposed depth of the ancient ocean. There can be no doubt, for example, that the strata *a*, Fig. 7., or those nearest to Monte Calvo, are older than those indicated by *b*, and these again were formed before *c*; but the vertical depth of gravel and sand in any one place cannot be proved to amount even to 1000 feet, although it may perhaps be much greater, yet probably never exceeding at any point 3000 or 4000 feet. But were we to assume that all the strata were once horizontal, and that their present dip or inclination was due to subsequent movements, we should then be forced to conclude, that a sea 9 miles deep had been filled up with alternate layers of mud and pebbles thrown down one upon another.

In the locality now under consideration, situated a few miles to the west of Nice, there are many geological data which there is not room to detail in this place, all leading to the opinion, that when the deposit of the Magnan was formed, the shape and outline of the alpine declivities and the shore greatly resembled what we now behold at many points in the neighbourhood. That the beds *a*, *b*, *c*, *d*, are of comparatively modern date is proved by this fact, that in seams of loamy marl intervening between the pebbly beds are fossil shells, half of which belong to species now living in the Mediterranean.

Ripple mark. — The ripple mark, so common on the surface of sandstones of all ages (see Fig. 8.), and which is so often seen on the sea-shore at low tide, seems to originate in the drifting of materials along the bottom of the water, in a manner very similar to that which may explain the inclined layers above described. This ripple is not entirely confined to the beach between high and low water mark, but is also produced on sands which are constantly covered by water. Similar undulating ridges and furrows may also be sometimes seen on the surface of drift snow and blown sand. The following is the manner in which I once observed the motion of the air to produce this effect on a large extent of level beach, exposed at low tide near Calais. Clouds of fine white sand were

blown from the neighbouring dunes, so as to cover the shore, and whiten a dark level surface of sandy

Fig. 8.



Slab of ripple-marked (new red) sandstone from Cheshire.

mud, and this fresh covering of sand was beautifully rippled. On levelling all the small ridges and furrows of this ripple over an area several yards square, I saw them perfectly restored in about ten minutes, the general direction of the ridges being always at right angles to that of the wind. The restoration began by the appearance here and there of small detached heaps of sand, which soon lengthened and joined together, so as

to form long sinuous ridges with intervening furrows. Each ridge had one side slightly inclined,

Fig. 9.

and the other steep; the lee-side being always steep, as *b*, *c*, — *d*, *e*; the windward-side a gentle slope, as *a*, *b*, — *c*, *d*, Fig. 9. When a gust of wind blew with sufficient force to drive along a cloud of sand, all the ridges were seen to be in motion at once, each encroaching on the furrow before it, and, in the course of a few minutes, filling the place which the furrows had occupied. The mode of advance was by the continual drifting of grains of sand up the slopes *a b* and *c d*, many of which grains, when they arrived at *b* and *d*, fell over the scarps *b c* and *d e*, and were under shelter from the wind; so that they remained stationary, resting, according to their shape and momentum, on different parts of the descent, and a few only rolling to the bottom. In this manner each ridge was distinctly seen to move slowly on as often as the force of the wind augmented. Occasionally part of a ridge, advancing more rapidly than the rest, overtook the ridge immediately before it, and became confounded with it, thus causing those bifurcations and branches which are so common, and two of which are seen in the slab, Fig. 8. We may observe this configuration in sandstones

of all ages, and in them also, as now on the sea-coast, we may often detect two systems of ripples interfering with each other; one more ancient and half effaced, and a newer one, in which the grooves and ridges are more distinct, and in a different direction. This crossing of two sets of ripples arises from a change of wind, and the new direction in which the waves are thrown on the shore.

CHAPTER III.

ARRANGEMENT OF FOSSILS IN STRATA—FRESHWATER AND MARINE.

Successive deposition indicated by fossils — Limestones formed of corals and shells — Proofs of gradual increase of strata derived from fossils — Serpula attached to spatangus — Wood bored by teredina — Tripoli and semi-opal formed of infusoria — Chalk derived principally from organic bodies — Distinction of freshwater from marine formations — Genera of freshwater and land shells — Rules for recognizing marine testacea — Gyrogonite and chara — Freshwater fishes — Alternation of marine and freshwater deposits — Lym-Fiord.

Having in the last chapter considered the forms of stratification so far as they are determined by the arrangement of inorganic matter, we may now turn our attention to the manner in which organic remains are distributed through stratified deposits. We should often be unable to detect any signs of stratification or of successive deposition, if particular kinds of fossils did not occur here and there at certain depths in the mass. At one level, for example, bivalve shells of some one or more species predominate; at another, some univalve shell, and at a third, corals; while in some formations we find layers of vegetable matter separating strata.

It may appear inconceivable to a beginner how mountains, several thousand feet thick, can have become filled with fossils from top to bottom; but the difficulty is removed, when he reflects on the origin of stratification, as explained in the last chapter, and allows sufficient time for the accumulation of sediment. He must never lose sight of the fact that, during the process of deposition, each separate layer was once the uppermost, and covered immediately by the water in which aquatic animals lived. Each stratum, in fact, however far it may now lie beneath the surface, was once in the state of loose sand or soft mud at the bottom of the sea, in which shells and other bodies easily became enveloped.

By attending to the nature of these remains, we are often enabled to determine whether the deposition was slow or rapid, whether it took place in a deep or shallow sea, near the shore or far from land, and whether the water was salt, brackish, or fresh. Some limestones consist almost exclusively of corals, and their position has evidently been determined by the manner in which the zoophytes grew; for if the stratum be horizontal, the round spherical head of certain species is uppermost, and the point of attachment directed downwards. This arrangement is sometimes repeated throughout a great succession of strata. From what we know of the growth of

similar zoophytes in modern reefs, we infer that the rate of increase was extremely slow, and some of the fossils must have flourished for ages like forest trees, before they attained so large a size. During these ages, the water remained clear and transparent, for such zoophytes cannot live in turbid water.

In like manner, when we see thousands of full-grown shells dispersed every where throughout a long series of strata, we cannot doubt that time was required for the multiplication of successive generations; and the evidence of slow accumulation is rendered more striking from the proofs, so often discovered, of fossil bodies having lain for a time on the floor of the ocean after death, before they were imbedded in sediment. Nothing, for example, is more common than to see fossil oysters in clay, with serpulæ, acorn shells, corals, and other creatures, attached to the inside of the valves, so that the mollusk was certainly not buried in argillaceous mud the moment it died. There must have been an interval during which it was still surrounded with clear water, when the testacea, now adhering to it, grew from an embryo state to full maturity. Attached shells which are merely external, like some of the serpulæ in the annexed figure (Fig. 10.), may often have grown upon an oyster or other shell while the animal within was still living; but if they are found on

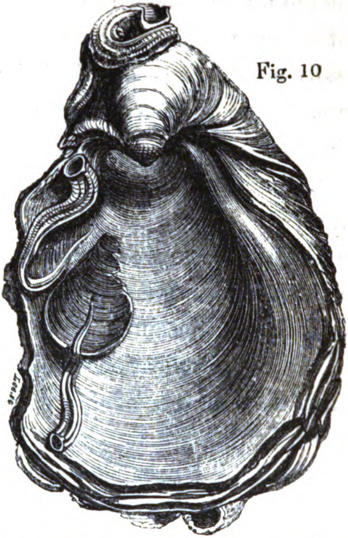


Fig. 10

Fossil Gryphæa, covered both on the outside and inside with fossil serpulæ.

the inside, it could only happen after the death of the inhabitant of the shell which affords the support. Thus, in Fig. 10., it will be seen that two serpulæ have grown on the interior, one of them exactly on the place where the adductor muscle of the *Gryphæa* (a kind of oyster) was fixed.

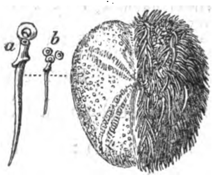
Some fossil shells, even if simply attached to the *outside* of others, bear full testimony to the conclusion above alluded to, namely, that an interval elapsed between the death of the creature to whose shell they adhere, and the burial of the same in mud or sand. The sea-urchins, or

Echini, so abundant in white chalk, afford a good illustration. It is well known that these animals, when living, are invariably covered with numerous spines, which serve as organs of motion, and are supported by rows of tubercles, which last are only seen after the death of the sea-urchin, when the spines have dropped off. In Fig. 12. a living

Fig. 11.

Serpula attached to fossil Spatangus from the chalk.

Fig. 12.



Recent Spatangus with the spines removed from one side.

b. Spine and tubercles, nat. size.
a. The same magnified.

species of *Spatangus*, common on our coast, is represented with one half of its shell stripped of the spines. In Fig. 11. a fossil of the same genus from the white chalk of England shows the naked surface which the individuals of this family exhibit when denuded of their bristles. The full-grown *Serpula*, therefore, which now adheres externally, could not have begun to grow till the *Spatangus* had died, and the spines were detached.

Now the series of events here attested by a single fossil may be carried a step farther. Thus, for example, we often meet with a sea-urchin in

the chalk (see Fig. 13.), which has fixed to it the lower valve of a *Crania*, a genus of bivalve mollusca. The upper valve (*b*, Fig. 13.) is almost invariably wanting, though occasionally found in a perfect state of preservation in white chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines, which were carried away. Then the young *Crania* adhered to the bared shell, grew, and perished in its turn; after which the upper valve was separated from the lower before the *Echinus* became enveloped in chalky mud.

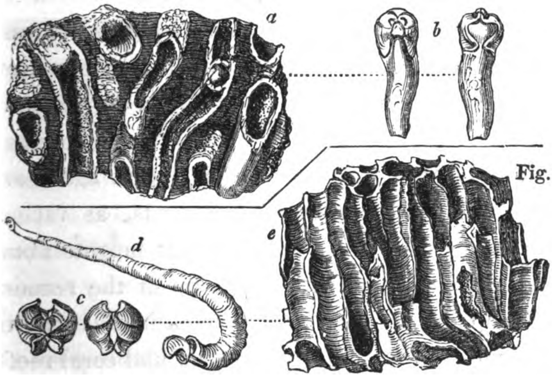
Fig. 13.

a. Echinus from the chalk, with lower valve of the *Crania* attached.
b. Upper valve of the *Crania* detached.

It may be well to mention one more illustration of the manner in which single fossils may sometimes throw light on a former state of things, both in the bed of the ocean and on some adjoining land. We meet with many fragments of wood bored by ship-worms at various depths in the clay on which London is built. Entire branches and stems of trees, several feet in length, are sometimes dug out, drilled all over by the holes of these borers, the tubes and shells of the mollusk still remaining in the cylindrical hollows. In Fig. 15., *e*, a representation is given of a piece of recent wood pierced by the *Teredo navalis*, or common shipworm, which destroys wooden piles and ships.

When the cylindrical tube *d* has been extracted from the wood, a shell is seen at the larger extremity, composed of two pieces, as shown at *c*. In like manner, a piece of fossil wood (*a*, Fig. 14.) has been perforated by an animal of a kindred but extinct genus, called *Teredina* by Lamarck. The calcareous tube of this mollusk was united

Fig. 14.



Fossil and recent wood drilled by perforating mollusca.

Fig. 14. *a.* Fossil wood from London clay, bored by *Teredina.*
b. Shell and tube of *Teredina personata,* the right-hand figure the ventral, the left the dorsal view.

Fig. 15. *e.* Recent wood bored by *Teredo.*
d. Shell and tube of *Teredo navalis,* from the same.
c. Anterior and posterior view of the valves of same detached from the tube.

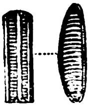
and as it were soldered on to the valves of the shell (*b*), which therefore cannot be detached from the tube, like the valves of the recent *Teredo.*

The wood in this fossil specimen is now converted into a stony mass, a mixture of clay and lime; but it must once have been buoyant and floating in the sea, when the *Teredinæ* lived upon it, perforating it in all directions. Again, before the infant colony settled upon the drift wood, the branch of a tree must have been floated down to the sea by a river, uprooted, perhaps, by a flood, or torn off and cast into the waves by wind: and thus our thoughts are carried back to a prior period, when the tree grew for years on dry land, enjoying a fit soil and climate.

It has been already remarked that there are rocks in the interior of continents, at various depths in the earth, and at great heights above the sea, almost entirely made up of the remains of zoophytes and testacea. Such masses may be compared to modern oyster-beds and coral reefs; and, like them, the rate of increase must have been extremely gradual. But there are a variety of stony deposits in the earth's crust, now proved to have been derived from plants and animals, of which the organic origin was not suspected until of late years, even by naturalists. Great surprise was therefore created by the recent discovery of Professor Ehrenberg of Berlin, that a certain kind of siliceous stone, called tripoli, was entirely composed of millions of the skeletons or cases of

microscopic animalcules. The substance alluded to has long been well known in the arts, being used in the form of powder for polishing stones and metals. It has been procured, among other places, from Bilin, in Bohemia, where a single stratum, extending over a wide area, is no less than 14 feet thick. This stone, when examined with a powerful microscope, is found to consist of the siliceous cases of infusoria, united together without any

Fig. 16.

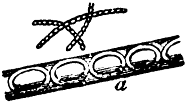


Bacillaria vulgaris?

Fig. 17.

Gaillonella distans.

Fig. 18.



Gaillonella ferruginea.

These figures are magnified nearly 300 *times, except the lower figure of G. ferruginea* (*Fig.* 18. *a*), *which is magnified* 2000 *times.*

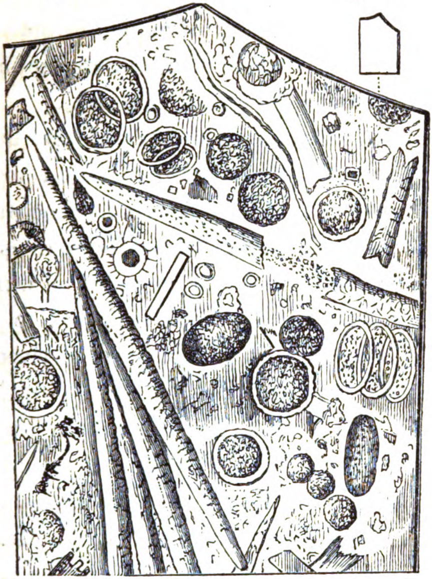
visible cement. It is difficult to convey an idea of their extreme minuteness; but Ehrenberg estimates that in the Bilin tripoli there are 41,000 millions of individuals of the *Gaillonella distans* (see Fig. 17.) in every cubic inch, which weighs about 220 grains, or about 187 millions in a single grain. At every stroke, therefore, that we make with this polishing powder, several millions, perhaps tens of millions, of perfect fossils are crushed to atoms.

The shells or shields of these infusoria are of pure silex, and their forms are various, but very

marked and constant in particular genera and species. Thus, in the family *Bacillaria* (see Fig. 16.), the fossil species preserved in tripoli are seen to exhibit the same divisions and transverse lines which characterize the living shells of kindred form. With these, also, the siliceous spiculæ or internal supports of the freshwater sponge, or *Spongilla* of Lamarck, are sometimes intermingled (see the needle-shaped bodies in Fig. 20.). These flinty cases and spiculæ, although hard, are very fragile, breaking like glass, and are therefore admirably adapted, when rubbed, for wearing down into a fine powder fit for polishing the surface of metals.

Besides the tripoli, which is formed exclusively of infusoria, there occurs in the upper part of the great stratum at Bilin another heavier and more compact stone, a kind of semi-opal, in which innumerable parts of infusoria and spiculæ of the *Spongilla* are filled with, and cemented together by, siliceous matter. It is supposed that the shells of the more delicate animalcules have been dissolved by water, and have thus given rise to this opal, in which the more durable fossils are preserved like insects in amber. This opinion is confirmed by the fact that the small shells decrease in number and sharpness of outline in proportion as the opaline cement increases in quantity.

Fig. 20. Fig. 19.



Fragment of semi-opal from the great bed of tripoli, Bilin.

Fig. 19. Natural size.
Fig. 20. The same magnified, showing circular articulations of a species of *Gaillonella*, and spiculæ of *Spongilla*.

In the Bohemian tripoli above described, as in that of Planitz in Saxony, the species of infusoria are freshwater; but in other countries, as in the tripoli of the Isle of France, they are of marine species, and they all belong to formations of the *tertiary* period, which will be spoken of hereafter.

A well-known substance, called bog-iron ore, often met with in peat-mosses, has also been shown by Ehrenberg to consist of innumerable articu-

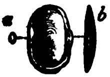
lated threads, of a yellow ochre colour, composed partly of flint and partly of oxide of iron. These threads are the cases of a minute animalcule, called *Gaillonella ferruginea* (Fig. 18.).

It is clear that much time must have been required for the accumulation of strata to which countless generations of infusoria have contributed their shells; and these discoveries lead us naturally to suspect that other deposits, of which the materials have usually been supposed to be inorganic, may in reality have been derived from microscopic organic bodies. That this is the case with the white chalk, has often been imagined, this rock having been observed to abound in a variety of marine fossils, such as shells, echini, corals, sponges, crustacea, and fishes. Mr. Lonsdale, on examining, in Oct. 1835, in the museum of the Geological Society of London, portions of white chalk from different parts of England, found, on carefully pulverizing them in water, that what appear to the eye simply as white grains were, in fact, well-preserved fossils. He obtained about a thousand of these from each pound weight of chalk, some being fragments of minute corallines, others entire Foraminifera and Cytherinæ. The annexed drawings will give an idea of the beautiful forms of many of these bodies. The figures *a a* represent their natural size, but, minute as they seem, the smallest of

them, such as *a*, Fig. 24., are gigantic in comparison with the cases of infusoria before men-

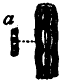
Cytherinæ and Foraminifera from the chalk.

Fig. 21.



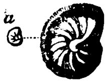
Cytherina.

Fig. 22.



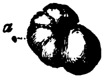
Portion of Nodosaria.

Fig. 23.



Lenticulina, Lam. (*Operculina*, D'Orb.)

Fig. 24.



Discorbis.

tioned. It has, moreover, been lately discovered, by Ehrenberg (1839), that the chambers into which these Foraminifera are divided are actually often filled with thousands of well preserved infusoria, and other microscopic bodies, which abound in every minute grain of chalk. The bodies alluded to are calcareous; but others have been detected in the flints of the chalk, which, like the infusoria in tripoli, are siliceous. These forms are especially apparent in the white coating of flints, often accompanied by innumerable needle-shaped spiculæ of sponges; and the same are occasionally visible in the central parts of chalk flints where they are of a lighter colour. After reflecting on these discoveries, we are naturally led on to conjecture that, as the formless cement in the semi-opal of Bilin has been derived from the decomposition of animal remains, so also even those parts of chalk flints in which no organic structure can be recognized

may nevertheless have constituted a part of microscopic animalcules.

"The dust we tread upon was once alive!"—BYRON.

How faint an idea does this exclamation of the poet convey of the real wonders of nature! for here we discover proofs that the calcareous and siliceous dust of which hills are composed has not only been once alive, but almost every particle, albeit invisible to the naked eye, still retains the organic structure which, at periods of time incalculably remote, was impressed upon it by the powers of life.

As I have dwelt upon the proofs of the slowness with which fossiliferous strata in general have been produced, I may remark that some writers have argued, from the appearances of certain deposits containing coal, that sedimentary rocks of great thickness have been accumulated with rapidity. This conclusion has been drawn chiefly from a remarkable phenomenon,—the position of the trunks of fossil trees intersecting obliquely, and often at right angles, the planes of many strata. For a full examination of this question, the reader is referred to the chapter on the carboniferous formations, in the sequel; and I shall merely say here, that, although partial deposits have been thrown down in the spots where these fossil trees occur in a comparatively short lapse of time, yet

we can by no means infer that a similar rate of increase of carboniferous rocks prevailed simultaneously over a wide area. On the other hand, the vegetable origin of coal is now universally admitted by geologists; and, when we discuss the probable manner in which the terrestrial plants from which it was derived were imbedded in marine shale and sandstone, we shall find it necessary to suppose a long succession of operations.

Freshwater and marine fossils. — Strata, whether deposited in salt or fresh water, have the same forms; but the fossils are very different in the two cases, because the aquatic animals which frequent lakes and rivers are distinct from those inhabiting the sea. In the northern part of the Isle of Wight is a formation, composed of marl and limestone, more than fifty feet thick, in which the shells are principally, if not all, of extinct species. Yet we recognize their freshwater origin, because they are of the same genera as those now abounding in ponds and lakes, either in our own country or in warmer latitudes.

In many parts of France, as in Auvergne, for example, strata of limestone, marl, and sandstone occur, hundreds of feet thick, which contain exclusively freshwater and land shells, together with the remains of terrestrial quadrupeds. The number of land shells scattered through some of these freshwater deposits is exceedingly great; and there

are even districts where the rocks scarcely contain any other fossils except snail-shells (*helices*); as, for instance, the limestone on the left bank of the Rhine, between Mayence and Worms, at Oppenheim, Findheim, Budenheim, and other places. In order to account for this phenomenon, the geologist has only to examine the small deltas of torrents which enter the Swiss lakes when the waters are low, such as the newly-formed plain where the Kander enters the Lake of Thun. He there sees sand and mud strewed over with innumerable dead land shells, which have been brought down from valleys in the Alps in the preceding spring, during the melting of the snows. Again, if we search the sands on the borders of the Rhine, in the lower part of its course, we find countless land shells mixed with others of species belonging to lakes, stagnant pools, and marshes. These individuals have been washed away from the alluvial plains of the great river and its tributaries, some from mountainous regions, others from the low country.

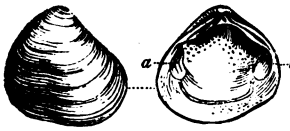
Although freshwater formations are often of great thickness, yet they are usually very limited in area when compared to marine deposits, just as lakes and estuaries are of small dimensions in comparison with seas.

We may distinguish a freshwater formation, first, by the absence of many fossils almost invari-

ably met with in marine strata. For example, there are no corals, no sea-urchins, and scarcely any other zoophytes; no chambered shells, such as the nautilus, nor microscopic Foraminifera. But it is chiefly by attending to the forms of the mollusca that we are guided in determining the point in question. In a freshwater deposit, the number of individual shells is often as great, if not greater, than in a marine stratum; but there is a smaller variety of species and genera. This might be anticipated from the fact that the genera and species of recent freshwater and land shells are few when contrasted with the marine. Thus, the genera of true mollusca according to Blainville's system, excluding those of extinct species and those without shells, amount to about 200 in number, of which the terrestrial and freshwater genera scarcely form more than a sixth.*

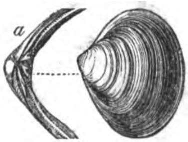
Almost all bivalve shells, or those of acephalous mollusca, are marine, about ten only out of

Fig. 25.



Cyclas obovata; fossil. Hants.

Fig. 26.



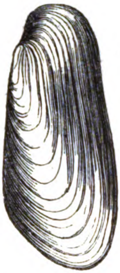
Cyrena trigonula; fossil. Grays, Essex.

ninety genera being freshwater. Among these last, the four most common forms, both recent

* See Synoptic Table in Blainville's Malacologie.

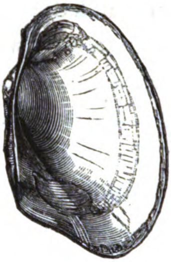
and fossil, are *Cyclas*, *Cyrena*, *Unio*, and *Anodonta* (see figures); the two first and two last of which are so nearly allied as to pass into each other.

Fig. 27.



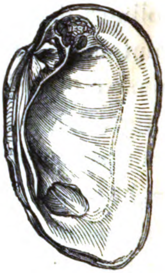
Anodonta Cordierii; fossil. Paris.

Fig. 28.



Anodonta latimarginatus; recent. Bahia.

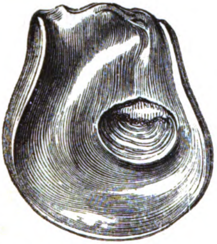
Fig. 29.



Unio littoralis; recent. Auvergne.

Lamarck divided the bivalve mollusca into the *Dimyary*, or those having two large muscular impressions in each valve, as *a b* in the Cyclas, Fig. 25., and the *Monomyary*, such as the oyster and scallop, in which there is only one of these impressions, as is seen in Fig. 30. Now, as none of these last, or the unimuscular bivalves, are freshwater, we may at once presume a deposit in which we find any of them to be marine.

Fig. 30.



Gryphæa incurva, Sow. (*G. arcuata*, Lam.) upper valve. Lias.

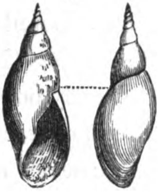
The univalve shells most characteristic of fresh-

water deposits are, *Planorbis*, *Limnea*, and *Paludina*. (See figures.) But to these are occasionally

Fig. 31.

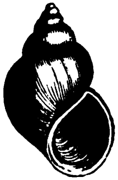
Planorbis euomphalus; fossil. Isle of Wight.

Fig. 32.



Limnea longiscata; fossil. Hants.

Fig. 33.



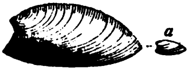
Paludina lenta; fossil. Hants.

added *Physa*, *Succinea*, *Ancylus*, *Valvata*, *Melanopsis*, *Melania*, and *Neritina*. (See figures.)

Fig. 34.

Succinea amphibia; fossil. Loess, Rhine.

Fig. 35.



Ancylus elegans; fossil. Hants.

Fig. 36.

Valvata; fossil. Grays, Essex.

Fig. 37.

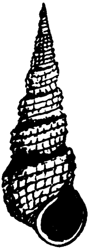
Physa hypnorum; recent.

In regard to one of these, the *Ancylus* (Fig. 35.), Mr. Gray observes that it sometimes differs

Fig. 38.

Auricula; recent. Ava.

Fig. 39.

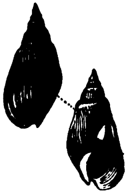


Melania inquinata. Paris Basin.

Fig. 40.

Physa columnaris. Paris Basin.

Fig. 41.

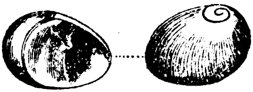


Melanopsis buccinoidea; recent. Asia.

in no respect from the marine *Siphonaria*, except in the animal. The shell, however, of the *Ancylus* is usually thinner.*

Some naturalists include *Neritina* (Fig. 42.) and the marine *Nerita* (Fig. 43.) in the same genus, it being scarcely possible to distinguish the two by good generic characters. But, as a general rule, the fluviatile species are smaller, smoother,

Fig. 42.



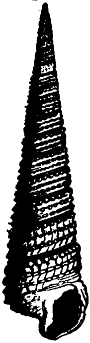
Neritina globulus. Paris basin.

Fig. 43.

Nerita granulosa. Paris basin.

and more globular than the marine; and they have never, like the *Neritæ*, the inner margin of the outer lip toothed or crenulated. (See Fig. 43.)

Fig. 44.



Cerithium cinctum. Paris basin.

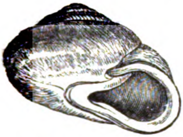
A few genera, among which *Cerithium* (Fig. 44.) is the most abundant, are common both to rivers and the sea, having species peculiar to each. Other genera, like *Auricula* (Fig. 38.), are amphibious, frequenting marshes especially near the sea.

The terrestrial shells are all univalves. The most abundant genera among these, both in a recent and fossil state, are *Helix* (Fig. 45.), *Cyclostoma*, *Pupa* (Fig. 46.),

* Gray, Phil. Trans., 1835, p. 302.

Clausilia (Fig. 47.), *Bulimus* (Fig. 48.), and *Achatina;* which two last are nearly allied and pass into each other.

Fig. 45.



Helix Turonensis. Faluns, Touraine.

Fig. 46.

Pupa tridens. Loess.

Fig. 47.

Clausilia bidens. Loess.

Fig. 48.

Bulimus lubricus. Loess, Rhine.

The *Ampullaria* (Fig. 49.) is another genus of shells, inhabiting rivers and ponds in hot countries. Many fossil species have been referred to this genus, but they have been found chiefly in marine formations, and are suspected by some conchologists to belong to *Natica* and other marine genera.

Fig. 49.

Ampullaria glauca, from the Jumna.

All univalve shells of land and freshwater species with the exception of *Melanopsis* (Fig. 41.), and *Achatina*, which has a slight indentation, have entire mouths; and this circumstance may often serve as a convenient rule for distinguishing freshwater from marine strata; since, if any univalves occur of which the mouths are not entire, we may presume that the formation is marine. The aperture is said to be entire in such shells as the *Am-*

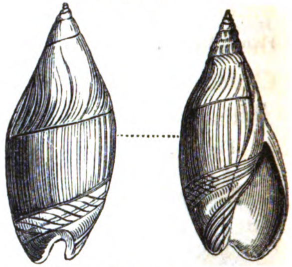
pullaria and the land shells figured in page 65., when its outline is not interrupted by an indentation or notch such as that in *Ancillaria* (Fig. 51.); or is not prolonged into a canal, as that seen at *a* in *Pleurotoma* (Fig. 50.).

The mouths of a large proportion of the marine univalves have either these notches or canals, and

Fig. 50.

Pleurotoma rotata. Subap. hills, Italy.

Fig. 51.



Ancillaria subulata. London clay.

almost all these species are carnivorous; whereas nearly all testacea having entire mouths, are plant-eaters, whether the species be marine, fresh-water, or terrestrial.

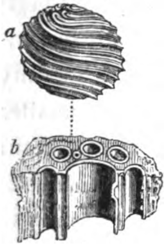
There is, however, one genus which affords an occasional exception to one of the above rules. The *Cerithium* (Fig. 44.), although provided with a short canal, comprises some species which inhabit salt, others brackish, and others fresh water, and they are said to be all plant-eaters.

Among the fossils very common in freshwater deposits, are the shells of *Cypris*, a minute crus-

taceous animal, having a shell much resembling that of the bivalve mollusca.* Many minute living species of this genus swarm in lakes and stagnant pools in Great Britain; but their shells are not, if considered separately, conclusive as to the freshwater origin of a deposit, because another kindred genus of the same order, the *Cytherina* of Lamarck (see Fig. 21. p. 57.), inhabits salt water; and, although the animal differs slightly, the shell is undistinguishable from that of the *Cypris*.

The seed-vessels of *Chara*, a genus of aquatic plants, are very frequent in freshwater strata. These seed-vessels were called, before their true

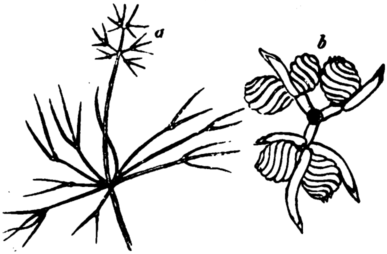
Fig. 52.



Chara medicaginula; fossil. Isle of Wight.

a. Seed-vessel, magnified 20 diameters.
b. Stem, magnified.

Fig. 53.



Chara elastica; recent. Italy.

a. Sessile seed-vessel between the division of the leaves of the female plant.
b. Transverse section of a branch, with five seed-vessels magnified, seen from below upwards.

* For figures of recent species, see Index, "*Cypris*."

nature was known, gyrogonites, and were supposed to be shells. (See Fig. 52. *a*.)

The *Charæ* inhabit the bottom of lakes and ponds, and flourish mostly where the water is charged with carbonate of lime. Their seed-vessels are covered with a very tough integument, capable of resisting decomposition; to which circumstance we may attribute their abundance in a fossil state. The annexed figure (Fig. 53.) represents a branch of one of many new species found by Professor Amici in the lakes of northern Italy. The seed-vessel in this plant is more globular than in the British *Charæ*, and therefore more nearly resembles in form the extinct fossil species found in England, France, and other countries. The stems, as well as the seed-vessels, of these plants occur both in modern shell marl and in ancient freshwater formations. They are generally composed of a large tube surrounded by smaller tubes; the whole stem being divided at certain intervals by transverse partitions or joints. (See *b*, Fig. 52.)

It is not uncommon to meet with layers of vegetable matter, impressions of leaves, and branches of trees, in strata containing freshwater shells; and we also find occasionally the teeth and bones of land quadrupeds, of species now unknown. The manner in which such remains are occasionally carried by rivers into lakes, especially during

floods, has been fully treated of in the "Principles of Geology." *

The remains of fish are occasionally useful in determining the freshwater origin of strata. Certain genera, such as carp, perch, pike, and loach, (*Cyprinus*, *Perca*, *Esox*, and *Cobitis*,) as also *Lebias*, being peculiar to freshwater. Other genera contain some freshwater and some marine species, as *Cottus*, *Mugil*, and *Anguilla*, or eel. The rest are either common to rivers and the sea, as the salmon; or are exclusively characteristic of salt water. The above observations respecting fossil fishes are applicable only to the more modern or tertiary deposits; for in the more ancient rocks the forms depart so widely from those of existing fishes, that it is very difficult, at least in the present state of science, to derive any positive information from icthyolites, respecting the element in which strata were deposited.

The alternation of marine and freshwater formations, both on a small and large scale, are facts well ascertained in geology. When it occurs on a small scale, it may have arisen from the alternate occupation of certain spaces by river water and the sea; for in the flood season the river forces back the ocean and freshens it over a large area, depositing at the same time its sediment; after which the salt water again returns, and, on re-

* See Index, "Fossilization."

suming its former place, brings with it sand, mud, and marine shells.

There are also lagoons at the mouths of many rivers, as the Nile and Mississippi, which are divided off by bars of sand from the sea, and which are filled with salt and fresh water by turns. They often communicate exclusively with the river for months, years, or even centuries; and then a breach being made in the bar of sand, they are for long periods filled with salt water.

The Lym-Fiord in Jutland offers an excellent illustration of analogous changes; for, in the course of the last thousand years, the western extremity of this long frith, which is 120 miles in length, including its windings, has been four times fresh and four times salt, a bar of sand between it and the ocean having been as often formed and removed. The last irruption of salt water happened in 1824, when the North Sea entered, killing all the freshwater shells, fish, and plants; and from that time to the present, the sea-weed *Fucus vesiculosus*, together with oysters and other marine mollusca, have succeeded the *Cyclas*, *Limnea*, *Paludina*, and *Charæ*.*

But changes like these in the Lym-Fiord, and those before mentioned as occurring at the mouths of great rivers, will only account for some cases

* See Principles, Index, "Lym-Fiord."

of marine deposits resting on freshwater strata. When we find, as in the south-east of England, a great series of freshwater beds, resting upon one marine formation of great thickness, and again covered by another more than 1000 feet thick, we shall find it necessary to seek for a different explanation of the phenomena.*

* See Chap. on Wealden.

CHAPTER IV.

CONSOLIDATION OF STRATA AND PETRIFACTION OF FOSSILS.

Chemical and mechanical deposits — Cementing together of particles — Hardening by exposure to air — Concretionary nodules — Consolidating effects of pressure — Mineralization of organic remains — Impressions and casts how formed — Fossil wood — Göppert's experiments — Precipitation of stony matter most rapid where putrefaction is going on — Source of lime in solution — Silex derived from decomposition of felspar — Proofs of the lapidification of some fossils soon after burial, of others when much decayed.

HAVING spoken in the preceding chapters of the forms of stratification, both as dependent on the deposition of inorganic matter and the distribution of fossils, I may next treat of the consolidation of stratified rocks, and the petrifaction of imbedded organic remains.

Chemical and mechanical deposits. — A distinction has been made by geologists between deposits of a chemical, and those of a mechanical, origin. By the latter name are designated beds of mud, sand, or pebbles produced by the action of running water, also accumulations of stones and scoriæ thrown out by a volcano, which have fallen into their present place by the force of gravitation.

But the matter which forms a chemical deposit has not been mechanically suspended in water, but in a state of solution until separated by chemical action. In this manner carbonate of lime is often thrown to the bottom of lakes and seas in a solid form, as may be well seen in many parts of Italy, where mineral springs abound, and where the calcareous stone, called travertin, is deposited. In these springs the lime is usually held in solution by an excess of carbonic acid, or by heat if it be a hot spring, until the water, on issuing from the earth, cools or loses part of its acid. The calcareous matter then falls down in a solid state, encrusting shells, fragments of wood and leaves, and binding them together.*

In coral reefs, large masses of limestone are formed by the stony skeletons of zoophytes; and these, together with shells, become cemented together by carbonate of lime, part of which is probably furnished to the sea-water by the decomposition of dead corals. Even shells of which the animals are still living, on these reefs, are very commonly found to be encrusted over with a hard coating of limestone.†

If sand and pebbles are carried by a river into the sea, and these are bound together immediately by carbonate of lime, the deposit may be described

* See Principles, Index, "Calcareous Springs," &c.

† Ibid. "Travertin," "Coral reefs," &c.

as of a mixed origin, partly chemical, and partly mechanical.

Now, the remarks already made in Chapter II. on the original horizontality of strata are strictly applicable to mechanical deposits, and only partially to those of a mixed nature. Such as are purely chemical may be formed on a very steep slope, or may even encrust the vertical walls of a fissure, and be of equal thickness throughout; but such deposits are of small extent, and for the most part confined to vein-stones.

Cementing of particles.—It is chiefly in the case of calcareous rocks that solidification takes place at the time of deposition. But there are many deposits in which a cementing process comes into operation long afterwards. We may sometimes observe, where the water of ferruginous or calcareous springs has flowed through a bed of sand or gravel, that iron or carbonate of lime has been deposited in the interstices between the grains or pebbles, so that in certain places the whole has been bound together into a stone, the same set of strata remaining in other parts loose and incoherent.

Proofs of a similar cementing action are seen in a rock at Kelloway in Wiltshire. A peculiar band of sandy strata, belonging to the group called Oolite by geologists, may be traced through several counties, the sand being for the most part loose

and unconsolidated, but becoming stony near Kelloway. In this district there are numerous fossil shells which have decomposed, having for the most part left only their casts. The calcareous matter hence derived has evidently served, at some former period, as a cement to the siliceous grains of sand, and thus a solid sandstone has been produced. If we take fragments of many other argillaceous grits, retaining the casts of shells, and plunge them into dilute muriatic or other acid, we see them immediately changed into common sand and mud; the cement of lime, derived from the shells, having been dissolved by the acid.

Traces of impressions and casts are often extremely faint. In some loose sands of recent date we meet with shells in so advanced a stage of decomposition as to crumble into powder when touched. It is clear that water percolating such strata may soon remove the calcareous matter of the shell; and, unless circumstances cause the carbonate of lime to be again deposited, the grains of sand will not be cemented together; in which case no memorial of the fossil will remain. The absence of organic remains from many aqueous rocks may be thus explained.

In what manner silex and carbonate of lime may become widely diffused in small quantities through the waters which permeate the earth's

crust will be spoken of presently, when the petrifaction of fossil bodies is considered; but I may remark here that such waters are always passing in the case of thermal springs from hotter to colder parts of the interior of the earth; and as often as the temperature of the solvent is lowered, mineral matter has a tendency to separate from it and solidify. Thus a stony cement is often supplied to any sand, pebbles, or fragmentary mixture. In some conglomerates, like the pudding-stone of Hertfordshire, pebbles of flint and grains of sand are united by a siliceous cement so firmly, that if a block be fractured the rent passes as readily through the pebbles as through the cement.

It is probable that many strata became solid at the time when they emerged from the waters in which they were deposited, and when they first formed a part of the dry land. A well-known fact seems to confirm this idea; by far the greater number of the stones used for building and road-making are much softer when first taken from the quarry than after they have been long exposed to the air. Hence it is found desirable to shape the stones which are to be used in architecture while they are yet soft and wet, and while they contain their "quarry-water," as it is called; also to break up stone intended for roads when soft, and then leave it to dry in the air for months that it may harden. Such induration may perhaps be

accounted for by supposing the water, which penetrates the minutest pores of rocks, to deposit on evaporation carbonate of lime, iron, silex, and other minerals previously held in solution. These particles, on crystallizing, would not only be deprived themselves of freedom of motion, but would also bind together other portions of the rock which before were loosely aggregated. On the same principle wet sand and mud become as hard as stone when frozen; because one ingredient of the mass, namely, the water, has crystallized, so as to hold firmly together all the separate particles of which the loose mud and sand were composed.

Dr. MacCulloch mentions a sandstone in Sky, which may be moulded like dough when first found; and another from China, which is compressible by the hand when immersed in water. But it is not merely these compounds which readily admit water to penetrate into them; some simple minerals, says the same writer, which are rigid and as hard as glass in our cabinets, are often flexible and soft in their native beds; this is the case with asbestos, sahlite, tremolite, and calcedony, and it is reported also to happen in the case of the beryl.*

The marl recently deposited at the bottom of Lake Superior, in North America, is soft, and often

* Dr. MacCulloch, Syst. of Geol. vol. i. p. 123.

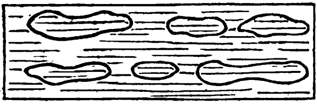
filled with fresh-water shells; but if a piece be taken up and dried, it becomes so hard that it can only be broken by a smart blow of the hammer. If the lake therefore was drained, such a deposit would be found to consist of strata of marlstone, like that observed in many ancient European formations, and like them containing fresh-water shells.*

It is probable that some of the heterogeneous materials which rivers transport to the sea may at once set under water, like the artificial mixture called pozzolana, which consists of fine volcanic sand charged with about 20 per cent. of iron, and the addition of a small quantity of lime. This substance hardens, and becomes a solid stone in water, and was used by the Romans in constructing the foundations of buildings in the sea.

Consolidation in these cases is brought about by the action of chemical affinity on finely comminuted matter previously suspended in water. After deposition similar particles seem to exert a mutual attraction on each other, and congregate together in particular spots, forming lumps, nodules, and concretions. Thus in many argillaceous deposits there are calcareous balls, or spherical concretions, ranged in layers parallel to the general stratification; an arrangement which took place after the shale or marl had been thrown down in successive

* Princ. of Geol., Index, "Superior, Lake."

Fig. 54.

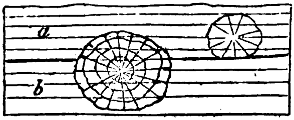


Calcareous nodules in Lias.

laminæ; for these laminæ are often traced in the concretions, remaining parallel to those of the surrounding unconsolidated rock. (See Fig. 54.) Such nodules of limestone have often a shell or other foreign body in the centre.*

Among the most remarkable examples of concretionary structure are those described by Professor Sedgwick as abounding in the magnesian limestone of the north of England. The spherical balls are of various sizes, from that of a pea to a diameter of several feet, and they have both a concentric and radiated structure, while at the same time the laminæ of original deposition pass uninterruptedly through them. In some cliffs this limestone resembles a great irregular pile of cannon balls. Some of the globular masses have their centre in one stratum, while a portion of their exterior passes through to the stratum above or below. Thus the larger spheroid in the annexed section

Fig. 55.



Spheroidal concretions in magnesian limestone.

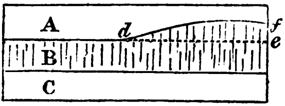
(Fig. 55.) passes from the stratum *b* upwards into *a*. In this instance we must suppose the deposition of a series of minor layers, first

* See De la Beche's Geological Researches, p. 95.

forming the stratum *b*, and afterwards the incumbent stratum *a;* then a movement of the particles took place, and the carbonates of lime and magnesia separated from the more impure and mixed matter forming the still unconsolidated parts of the stratum. Crystallization, beginning at the centre, must have gone on forming concentric coats, around the original nucleus without interfering with the laminated structure of the rock.

When the particles of rocks have been thus re-arranged by chemical forces, it is sometimes difficult or impossible to ascertain whether certain lines of division are due to original deposition or to the subsequent aggregation of similar particles.

Fig. 56.



Thus suppose three strata of grit, A, B, C. are charged unequally with calcareous matter, and that B is the most calcareous. If consolidation takes place in B, the concretionary action may spread upwards into a part of A, where the carbonate of lime is more abundant than in the rest; so that a mass, *d, e, f,* forming a portion of the superior stratum, becomes united with B into one solid mass of stone. The original line of division, *d, e,* being thus effaced, the line *d, f,* would generally be considered as the surface of the bed B, though not strictly a true plane of stratification.

Pressure and heat. — When sand and mud sink to the bottom of a deep sea, the particles are not pressed down by the enormous weight of the incumbent ocean; for the water, which becomes mingled with the sand and mud, resists pressure with a force equal to that of the column of fluid above. The same happens in regard to organic remains which are filled with water under great pressure as they sink, otherwise they would be immediately crushed to pieces and flattened. Nevertheless, if the materials of a stratum remain in a yielding state, and do not set or solidify, they will be gradually squeezed down by the weight of other materials successively heaped upon them, just as soft clay or loose sand on which a house is built may give way. By such downward pressure particles of clay, sand, and marl, may become packed into a smaller space, and be made to cohere together permanently.

Analogous effects of condensation may arise when the solid parts of the earth's crust are forced in various directions by those mechanical movements afterwards to be described, by which strata have been bent, broken, and raised above the level of the sea. Rocks of more yielding materials must often have been forced against others previously consolidated, and, thus compressed, may have acquired a new structure.

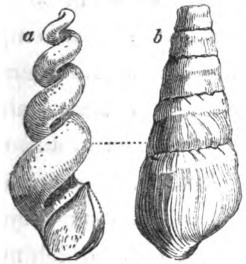
But the action of heat at various depths in the

earth is probably the most powerful of all causes in hardening sedimentary strata. To this subject I shall refer again when treating of the metamorphic rocks, and of the slaty and jointed structure.

Mineralization of organic remains.—The changes which fossil organic bodies have undergone since they were first imbedded in rocks, throw much light on the consolidation of strata. Fossil shells in some modern deposits have been scarcely altered in the course of centuries, having simply lost a part of their animal matter. But in other cases the shell has disappeared, and left an impression only of its exterior, or a cast of its interior form, or thirdly, a cast of the shell itself, the original matter of which has been removed. These different forms of fossilization may easily be understood if we examine the mud recently thrown out from a pond or canal in which there are shells. If the mud be argillaceous, it acquires consistency on drying, and on breaking open a portion of it we find that each shell has left impressions of its external form. If we then remove the shell itself, we find within a solid nucleus of clay, having the form of the interior of the shell. This form is often very different from that of the outer shell. Thus a cast such as *a*, Fig. 57., commonly called a fossil screw, would never be suspected by an inexperienced conchologist to be the internal shape

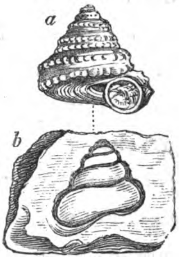
of the fossil univalve, *b*. Fig. 57. Nor should we have imagined at first sight that the shell *a* and

Fig. 57.



Phasianella Heddingtonensis, and cast of the same. Coral Rag.

Fig. 58.



Trochus Anglicus and cast. Lias.

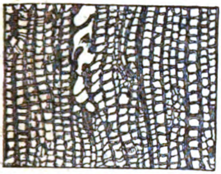
the cast *b*, Fig. 58., were different parts of the same fossil. The reader will observe in the last-mentioned figure (*b*, Fig. 58.), that an empty space shaded dark, which the *shell itself* once occupied, now intervenes between the enveloping stone and the cast of the smooth interior of the whorls. In such cases the shell has been dissolved and the component particles removed by water percolating the rock. If the nucleus were taken out a hollow mould would remain, on which the external form of the shell with its tubercles and striæ, as seen in *a*, Fig. 58., would be seen embossed. Now if the space alluded to between the nucleus and the impression, instead of being left empty, has been filled up with calcareous spar, pyrites, or other mineral, we then obtain from the mould an exact

cast both of the external and internal form of the original shell. In this manner silicified casts of shells have been formed; and if the mud or sand of the nucleus happen to be incoherent, or soluble in acid, we can then procure in flint an empty shell which is the exact counterpart of the original. This cast may be compared to a bronze statue, representing merely the superficial form, and not the internal organization; but there is another description of petrifaction by no means uncommon, and of a much more wonderful kind, which may be compared to certain anatomical models in wax, where not only the outward forms and features, but the nerves, blood-vessels, and other internal organs are also shown. Thus we find corals, originally calcareous, in which not only the general shape, but also the minute and complicated internal organization are retained in flint.

Such a process of petrifaction is still more remarkably exhibited in fossil wood, in which we often perceive not only the rings of annual growth, but all the minute vessels and medullary rays. Many of the minute pores and fibres of plants, and even those spiral vessels which in the living vegetable can only be discovered by the microscope, are preserved. Among many instances I may mention a fossil tree, seventy-two feet in length, found at Gosforth near Newcastle, in sandstone strata associated with coal. By cutting

a transverse slice so thin as to transmit light, and magnifying it about fifty-five times, the texture seen in Fig. 59. is exhibited. A texture equally minute and complicated has been observed in the wood of large trunks of fossil trees found in the Craigleith quarry near Edinburgh, where the stone was not in the slightest degree siliceous, but consisted chiefly of carbonate of lime, with oxide of iron, alumina, and carbon. In some examples the woody fibre is partially preserved, but it has entirely vanished from others.

Fig. 59.



Texture of a tree from the coal-strata, magnified. (Witham.)

In attempting to explain the process of petrifaction in such cases, we may first assume that strata are very generally permeated by water charged with minute portions of calcareous, siliceous, and other earths in solution. In what manner they become so impregnated will be afterwards considered. If an organic substance is exposed in the open air to the action of the sun and rain, it will in time putrefy, or be dissolved into its component elements, which consist chiefly of oxygen, hydrogen, and carbon. These will readily be absorbed by the atmosphere or be washed away by rain, so that all vestiges of the dead animal or plant disappear. But if the same substances be submerged in water, they decompose

more gradually; and if buried in earth, still more slowly, as in the familiar example of wooden piles or other buried timber. Now, if as fast as each particle is set free by putrefaction in a fluid or gaseous state, a particle equally minute of carbonate of lime, flint, or other mineral, is at hand and ready to be precipitated, we may imagine this inorganic matter to take the place just before left unoccupied by the organic molecule. In this manner a cast of the interior of certain vessels may first be taken, and afterwards the walls of the same may decay and suffer a like transmutation. Yet when the whole is lapidified, it may not form one homogeneous mass of stone or metal. Some of the original ligneous, osseous, or other organic elements may remain mingled in certain parts, or the lapidifying substance itself may be differently coloured at different times, or so crystallized as to reflect light differently, and thus the texture of the original body may be faithfully exhibited.

But the student will ask whether, on chemical principles, we have reason to expect that mineral matter will be thrown down precisely in those spots where organic decomposition is in progress? The following curious experiments may serve to illustrate this point. Professor Göppert of Breslau attempted recently to imitate the natural process of petrifaction. For this purpose he steeped

a variety of animal and vegetable substances in waters, some holding siliceous, others calcareous, others metallic matter in solution. He found that in the period of a few weeks, or even days, the organic bodies thus immersed were mineralized to a certain extent. Thus, for example, thin vertical slices of deal, taken from the Scotch fir (*Pinus sylvestris*), were immersed in a moderately strong solution of sulphate of iron. When they had been thoroughly soaked in the liquid for several days, they were dried and exposed to a red-heat until the vegetable matter was burnt up and nothing remained but an oxide of iron, which was found to have taken the form of the deal so exactly that even the dotted vessels peculiar to this family of plants, and resembling those in Fig. 59., were distinctly visible under the microscope.

Another accidental experiment has been recorded by Mr. Pepys in the Geological Transactions.* An earthen pitcher containing several quarts of sulphate of iron had remained undisturbed and unnoticed for about a twelvemonth in the laboratory. At the end of this time when the liquor was examined an oily appearance was observed on the surface, and a yellowish powder, which proved to be sulphur, together with a

* Vol. i. p. 399. first series.

quantity of small hairs. At the bottom were discovered the bones of several mice in a sediment consisting of small grains of pyrites, others of sulphur, others of crystallized green sulphate of iron, and a black muddy oxide of iron. It was evident that some mice had accidentally been drowned in the fluid, and by the mutual action of the animal matter and the sulphate of iron on each other, the metallic sulphate had been deprived of its oxygen; hence the pyrites and the other compounds were thrown down. Although the mice were not mineralized, or turned into pyrites, the phenomenon shows how mineral waters, charged with sulphate of iron, may be deoxydated on coming in contact with animal matter undergoing putrefaction, so that atom after atom of pyrites may be precipitated, and ready, under favourable circumstances, to replace the oxygen, hydrogen, and carbon into which the original body would be resolved.

The late Dr. Turner observes, that when mineral matter is in a "nascent state," that is to say, just liberated from a previous state of chemical combination, it is most ready to unite with other matter, and form a new chemical compound. Probably the particles or atoms just set free are of extreme minuteness, and therefore move more freely, and are more ready to obey any impulse of chemical affinity. Whatever be

the cause it clearly follows, as before stated, that where organic matter newly imbedded in sediment is decomposing, there will chemical changes take place most actively.

An analysis was lately made of the water which was flowing off from the rich mud deposited by the Hooghly river in the Delta of the Ganges after the annual inundation. This water was found to be highly charged with carbonic acid gas holding lime in solution.* Now if newly deposited mud is thus proved to be permeated by mineral matter in a state of solution, it is not difficult to perceive that decomposing organic bodies, naturally imbedded in sediment, may as readily become petrified as the substances artificially immersed by Professor Göppert in various fluid mixtures.

It is well known that the water of springs, or that which is continually percolating the earth's crust, is rarely free from a slight admixture either of iron, carbonate of lime, sulphur, flint, potash, or some other earthy, alkaline, or metallic ingredient. Hot springs in particular are copiously charged with one or more of these elements; and it is only in their waters that silex is found in abundance. In certain cases, therefore, especially in volcanic regions, we may imagine the flint of silicified wood and corals to have been supplied by the waters of thermal springs. In other

* Piddington, Asiat. Research. vol. xviii. p. 226.

instances, as in tripoli and chalk-flint, it may have been derived in great part, if not wholly, from the decomposition of infusoria, sponges, and other bodies. But even if this be granted, we have still to inquire whence a lake or the ocean can be constantly replenished with the siliceous matter so abundantly withdrawn from it by the secretions of these zoophytes.

In regard to carbonate of lime there is no difficulty, because not only are calcareous springs very numerous, but even rain-water has the power of dissolving a minute portion of the calcareous rocks over which it flows. Hence marine corals and mollusca may be provided by rivers with the materials of their shells and solid supports. But pure silex, even when reduced to the finest powder and boiled, is insoluble in water. Nevertheless Dr. Turner has well explained, in an essay on the chemistry of geology *, how the decomposition of felspar may be a source of silex in solution. He has remarked that the siliceous earth, which constitutes more than half the bulk of felspar, is intimately combined with alumine, potash, and some other elements. The alkaline matter of the felspar has a chemical affinity for water, as also for the carbonic acid which is more or less contained in the waters of most springs. The water there-

* Jam. Ed. New Phil. Journ. No. 30. p. 246.

fore carries away alkaline matter, and leaves behind a clay consisting of alumine and flint. But this residue of the decomposed mineral, which in its purest state is called porcelain-clay, is found to contain only a small proportion of the silica which existed in the original felspar. The other part therefore must have been dissolved and removed; and this can be accounted for in two ways, first, because silex when combined with an alkali is soluble in water; secondly, because silex in what is technically called its nascent state is also soluble in water. Hence an endless supply of silica is afforded to rivers and the waters of the sea. For the felspathic rocks are universally distributed, constituting as they do, so large a proportion of the volcanic, plutonic, and metamorphic formations. Even where they chance to be absent in mass, they rarely fail to occur in the superficial gravel or alluvial deposits of the basin of every large river.

The disintegration of mica also, another mineral which enters largely into the composition of granite and various sandstones, may yield silex which may be dissolved in water, for nearly half of this mineral consists of silica, combined with alumine, potash, and about a tenth part of iron. The oxidation of this iron in the air is the principal cause of the waste of mica.

We have still, however, much to learn before

the conversion of fossil bodies into stone is fully understood. Some phenomena seem to imply that the mineralization must proceed with considerable rapidity, for stems of a soft and succulent character, and of a most perishable nature, are preserved in flint; and there are instances of the complete silicification of the young leaves of a palm-tree when just about to shoot forth, and in that state which in the West Indies is called the cabbage of the palm.* It may, however, be questioned whether in such cases there may not have been some antiseptic quality in the water which retarded putrefaction, so that the soft parts of the buried substance may have remained for a long time without disintegration, like the flesh of bodies imbedded in peat.

Mr. Stokes has pointed out examples of petrifactions in which the more perishable, and others where the more durable portions of wood are preserved. These variations, he suggests, must doubtless have depended on the time when the lapidifying mineral was introduced. Thus, in certain silicified stems of palm-trees, the cellular tissue, that most destructible part, is in good condition, all signs of the hard woody fibre having disappeared, and the spaces once occupied by it being hollow or filled with agate. Here, petrifaction must have commenced soon after the wood

* Stokes, Geol. Trans. vol. v. p. 212. second series.

was exposed to the action of moisture, and the supply of mineral matter must then have failed, or the water have become too much diluted before the woody fibre decayed. But when this fibre is alone discoverable, we must suppose that an interval of time elapsed before the commencement of lapidification, during which the cellular tissue was obliterated. When both structures, namely, the cellular and the woody fibre, are preserved, the process must have commenced at an early period, and continued without interruption till it was completed throughout.*

* Stokes, Geol. Trans. vol. v. p. 212. second series.

CHAPTER V.

ELEVATION OF STRATA ABOVE THE SEA — HORIZONTAL AND INCLINED STRATIFICATION.

Why the position of marine strata, above the level of the sea, should be referred to the rising up of the land, not to the going down of the sea — Upheaval of extensive masses of horizontal strata — Inclined and vertical stratification — Anticlinal and synclinal lines — Bent strata in east of Scotland — Theory of folding by lateral movement — Creeps — Dip and strike — Structure of the Jura — Various forms of outcrop — Rocks broken by flexure — Inverted position of disturbed strata — Unconformable stratification — Fractures of strata — Polished surfaces — Faults — Appearance of repeated alternations produced by them — Origin of great faults.

Land has been raised, not the sea lowered. — It has been already stated that the aqueous rocks containing marine fossils extend over wide continental tracts, and are seen in mountain chains, rising to great heights above the level of the sea. Hence it follows, that what is now dry land was once under water. But if we admit this conclusion, we must imagine, either that there has been a general lowering of the waters of the ocean, or that the solid rocks, once covered by water, have been raised up bodily out of the sea, and have thus become dry land. The earlier geologists, finding

themselves reduced to this alternative, embraced the former opinion, assuming that the ocean was originally universal, and had gradually sunk down to its actual level, so that the present islands and continents were left dry. It seemed to them far easier to conceive that the water had gone down, than that solid land had risen upwards into its present position. It was, however, impossible to invent any satisfactory hypothesis to explain the disappearance of so enormous a body of water throughout the globe, it being necessary to infer that the ocean had once stood at whatever height marine shells might be detected. It moreover appeared clear, as the science of Geology advanced, that certain spaces on the globe had been alternately sea, then land, then estuary, then sea again, and, lastly, once more habitable land, having remained in each of these states for considerable periods. In order to account for such phenomena, without admitting any movement of the land itself, we are required to imagine several retreats and returns of the ocean; and even then our theory applies merely to cases where the marine strata composing the dry land are horizontal, leaving unexplained those more common instances where strata are inclined, curved, or placed on their edges, and evidently not in the position in which they were first deposited.

Geologists, therefore, were at last compelled to

have recourse to the other alternative, namely, the doctrine that the solid land has been repeatedly moved upwards or downwards, so as permanently to change its position relatively to the sea. There are several distinct grounds for preferring this conclusion. First, it will account equally for the position of those elevated masses of marine origin in which the stratification remains horizontal, and for those in which the strata are disturbed, broken, inclined, or vertical. Secondly, it is consistent with human experience that land should rise gradually in some places and be depressed in others. Such changes have actually occurred in our own days, and are now in progress, having been accompanied in some cases by violent convulsions, while in others they have proceeded so insensibly, as to have been ascertainable only by the most careful scientific observations, made at considerable intervals of time. On the other hand, there is no evidence from human experience of a lowering of the sea's level in any region, and the ocean cannot sink in one place without its level being depressed throughout the globe.

These preliminary remarks will prepare the reader to understand the great theoretical interest attached to all facts connected with the position of strata, whether horizontal or inclined, curved or vertical.

Now the first and most simple appearance is

where strata of marine origin occur above the level of the sea in horizontal position. Such are the strata which we meet with in the south of Sicily, filled with shells of the same species as now live in the Mediterranean. Some of these rocks rise to the height of more than 2000 feet above the sea. Other mountain masses might be mentioned, composed of horizontal strata of high antiquity, which contain fossil remains of animals wholly dissimilar from any now known to exist. In the south of Sweden, for example, near Lake Wener, the beds of a deposit, called Transition or Silurian by geologists, occur in as level a position as if they had recently formed part of the delta of a great river, and been left dry on the retiring of the annual floods. Aqueous rocks of about the same age extend over the lake-district of North America, and exhibit in like manner a stratification nearly undisturbed. The Table Mountain at the Cape of Good Hope is another example of highly elevated yet perfectly horizontal strata, no less than 3500 feet in thickness, and consisting of sandstone of very ancient date.

Instead of imagining that such fossiliferous rocks were always at their present level, and that the sea was once high enough to cover them, we suppose them to have constituted the ancient bed of the ocean, and that they were gradually uplifted to their present height. This idea, how-

ever startling it may at first appear, is quite in accordance, as before stated, with the analogy of changes now going on in certain regions of the globe. Thus in parts of Sweden, and the shores and islands of the Gulf of Bothnia, proofs have been obtained that the land is experiencing, and has experienced for centuries, a slow upheaving movement. Playfair argued in favour of this opinion in 1802, and in 1807 Von Buch, after his travels in Scandinavia, announced his conviction that a rising of the land was in progress. Celsius and other Swedish writers had, a century before, declared their belief, that a gradual change had, for ages, been taking place in the relative level of land and sea. They attributed the change to a fall of the waters both of the ocean and the Baltic. This theory, however, has now been refuted by abundant evidence; for the alteration of relative level has neither been universal nor every where uniform in quantity, but has amounted, in some regions, to several feet in a century, in others to a few inches; while in the southernmost part of Sweden, or the province of Scania, there has been actually a loss instead of a gain of land, buildings having gradually sunk below the level of the sea.*

* In the first three editions of my Principles of Geology, I expressed many doubts as to the validity of the alleged proofs of a gradual rise of land in Sweden; but after visiting

It appears from the observations of Mr. Darwin and others that very extensive regions of the continent of South America have been undergoing slow and gradual upheaval, by which the level plains of Patagonia, covered with recent marine shells, and the Pampas of Buenos Ayres have been exposed.* On the other hand, the gradual sinking of the west coast of Greenland, for the space of more than 600 miles from north to south, during the last four centuries, has been established by the observations of a Danish naturalist, Dr. Pingel. And while these proofs of continental elevation and subsidence, by slow and insensible movements, have been recently brought to light, the evidence has been daily strengthened of continued changes of level effected by violent convulsions in countries where earthquakes are frequent. There the rocks are rent from time to time, and heaved up or thrown down several feet at once, and disturbed in such a manner, that the original position of strata may, in the course of centuries, be modified to any amount.

It has also been shown by Mr. Darwin, that, in

that country, in 1834, I retracted these objections, and published a detailed statement of the observations which led me to alter my opinion in the Phil. Trans. 1835, Part I. See also the Principles, 4th and subsequent editions.

* See his Journal in Voyage of the Beagle.

those seas where circular coral islands abound, there is a slow and continued sinking of the submarine mountains on which the masses of coral are based; while in other areas of the South Sea, where coral is found above the sea level, and in inland situations, and where there are no circular or barrier reefs, the land is on the rise.*

It would require a volume to explain to the reader the various facts which establish the reality of these movements of land, whether of elevation or depression, whether accompanied by earthquakes or accomplished slowly and without local disturbance. Having treated fully of these subjects in the Principles of Geology, I shall assume, in the present work, that such changes are part of the actual course of nature; and when admitted, they will be found to afford a key to the interpretation of a variety of geological appearances, such as the elevation of horizontal, inclined, or disturbed marine strata, the superposition of freshwater to marine deposits, and many other phenomena, afterwards to be described. It will also appear, in the sequel, how much light the doctrine of a continued subsidence of land may throw on the manner in which a series of strata, formed in shallow water, may have accumulated to a great thickness. The excavation of

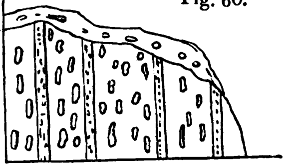
* Darwin, Proceedings of Geol. Soc. No. 51. p. 552., and his Journal in Voyage of the Beagle, vol. iii. p. 557.

valleys also, and other effects of *denudation*, of which I shall presently treat, can alone be understood when we duly appreciate the proofs, now on record, of the prolonged rising and sinking of land, throughout wide areas.

To conclude this subject, I may remind the reader, that were we to embrace the doctrine which ascribes the elevated position of marine formations, and the depression of certain freshwater strata, to oscillations in the level of the waters instead of the land, we should be compelled to admit that the ocean has been sometimes every where much shallower than at present, and at others more than three miles deeper.

Inclined stratification. — The most unequivocal evidence of a change in the original position of strata is afforded by their standing up perpendicularly on their edges, which is by no means a rare phenomenon, especially in mountainous countries. Thus we find in Scotland, on the southern skirts of the Grampians, beds of puddingstone alternating with thin layers of fine sand, all placed vertically to the horizon. When Saussure first observed certain conglomerates in a similar position in the Swiss Alps, he remarked that the pebbles, being for the

Fig. 60.



Vertical conglomerate and sandstone.

most part of an oval shape had their longer axes parallel to the planes of stratification, (See Fig. 60.) From this he inferred, that such strata must, at first, have been horizontal, each oval pebble having originally settled at the bottom of the water, with its flatter side parallel to the horizon, for the same reason that an egg will not stand on either end if unsupported. Some few, indeed, of the rounded stones in a conglomerate may afford exceptions to the above rule, for the same reason that we see on a shingle beach an occasional oval or flat-sided pebble resting on its end or edge; some pebbles having been forced along the bottom and against each other, may have settled in this position.

Vertical strata, when they can be traced continuously upwards or downwards for some depth, are almost invariably seen to be parts of great curves, which may have a diameter of a few yards, or of several miles. I shall first describe two curves of considerable regularity, which occur in Forfarshire, extending over a country twenty miles in breadth, from the foot of the Grampians to the sea near Arbroath.

The mass of strata here shown may be nearly 2000 feet in thickness, consisting of red and white sandstone, and various coloured shales, the beds being distinguishable into four principal groups, namely, No. 1. red marl or shale; No. 2. red

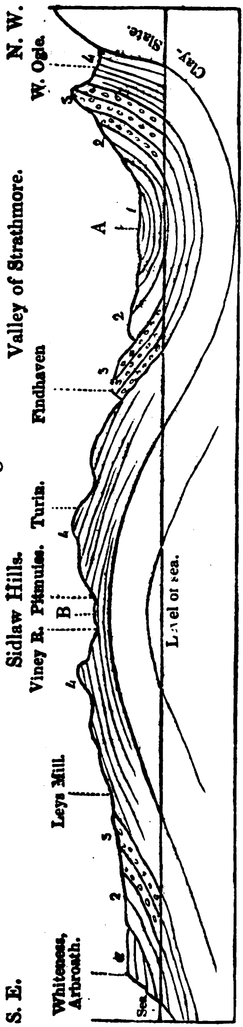


Fig. 61.

Section of Forfarshire, from N. W. to S. E., from foot of the Grampians to the sea at Arbroath (volcanic or trap rocks omitted). Length of section twenty miles.

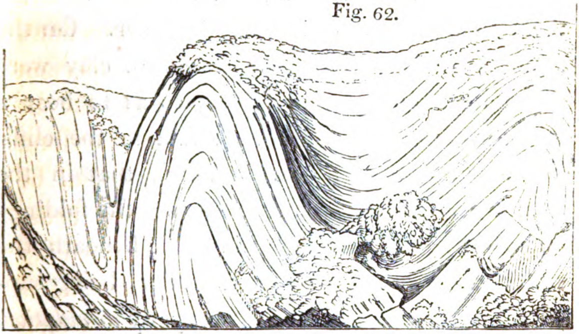
sandstone, used for building; No. 3. conglomerate; and No. 4., grey paving-stone, and tile-stone, with green and reddish shale, containing peculiar organic remains. A glance at the section will show that each of the formations 2, 3, 4, are repeated thrice at the surface, twice with a southerly and once with a northerly inclination or *dip*, and the beds in No. 1., which are nearly horizontal, are still brought up twice by a slight curvature to the surface, once on each side of A. Beginning at the north-west extremity, the tile-stones and conglomerates No. 4. and No. 3. are vertical, and they generally form a ridge parallel to the southern skirts

of the Grampians. The superior strata Nos. 2. and 1. become less and less inclined on descending to the valley of Strathmore, where the strata, having a concave bend, are said by geologists to lie in a "trough" or "basin." Through the centre of this valley runs an imaginary line A, called technically a "synclinal line," where the beds, which are tilted in opposite directions, may be supposed to meet. It is most important for the observer to mark such lines, for he will perceive by the diagram, that in travelling from the north to the centre of the basin, he is always passing from older to newer beds; whereas, after crossing the line A, and pursuing his course in the same southerly direction, he is continually leaving the newer, and advancing upon older strata. All the deposits which he had before examined begin then to recur in reversed order, until he arrives at the central axis of the Sidlaw hills, where the strata are seen to form an arch or *saddle*, having an *anticlinal* line, B, in the centre. On passing this line, and continuing towards the S. E., the formations 4, 3, and 2, are again repeated, in the same relative order of superposition, but with a northerly dip. At Whiteness (see diagram) it will be seen that the inclined strata are covered by a newer deposit, *a*, in horizontal beds. These are composed of red conglomerate and sand, and are newer than

any of the groups, 1, 2, 3, 4, before described, and rest *unconformably* upon strata of the sandstone group, No. 2.

An example of curved strata, in which the bends or convolutions of the rock are sharper and far more numerous within an equal space, has been

Fig. 62.



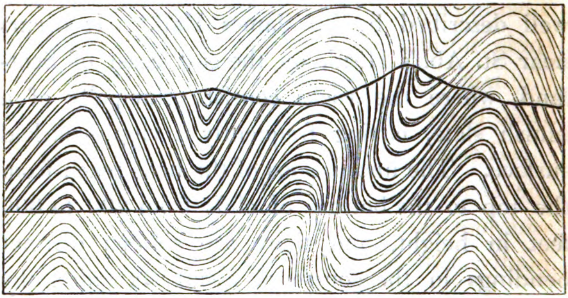
Curved strata of slate near St. Abb's Head, Berwickshire. (Sir J. Hall.)

well described by Sir James Hall.* It occurs near St. Abb's Head, on the east coast of Scotland, where the rocks consist principally of a bluish slate, having frequently a ripple-marked surface. The undulations of the beds reach from the top to the bottom of cliffs from 200 to 300 feet in height, and there are sixteen distinct bendings in the course of about six miles, the curvatures being alternately concave and convex upwards.

* Edin. Trans. vol. vii. pl. 3.

An experiment was made by Sir James Hall, with a view of illustrating the manner in which such strata, assuming them to have been originally horizontal, may have been forced into their present position. A set of layers of clay were placed under a weight, and their opposite ends pressed towards each other with such force as to cause them to approach more nearly together. On the removal of the weight, the layers of clay were found to be curved and folded, so as to bear a miniature resemblance to the strata in the cliffs. We must, however, bear in mind, that in the natural section or sea-cliff we only see the foldings imperfectly, one part being invisible beneath the sea, and the other, or upper portion, being supposed to have been carried away by *denudation*,

Fig. 63.



or that action of water which will be explained in the next chapter. The dark lines in the accompanying plan (Fig. 63.), represent what is actually

seen of the strata in part of the line of cliff alluded to; the fainter lines, that portion which is concealed beneath the sea level, as also that which is supposed to have once existed above the present surface.

We may still more easily illustrate the effects which a lateral thrust might produce on flexible strata, by placing several pieces of differently

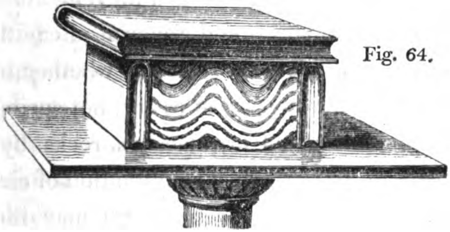


Fig. 64.

coloured cloths upon a table, and when they are spread out horizontally, cover them with a book. Then apply other books to each end, and force them towards each other. The folding of the cloths will exactly imitate those of the bent strata. (See Fig. 64.)

Whether the analogous flexures in stratified rocks have really been due to similar sideway movements is a question of considerable difficulty. It will appear when the volcanic and granitic rocks are described, that some of them have, when melted, been injected forcibly into fissures, while others, already in a solid state, have been protruded upwards through the incumbent

crust of the earth, by which a great displacement of flexible strata must have been caused.

But we also know by the study of regions liable to earthquakes, that there are causes at work in the interior of the earth capable of producing a sinking in of the ground, sometimes very local, but sometimes extending over a wide area. The frequent repetition, or continuance throughout long periods, of such downward movements seems to imply the formation and renewal of cavities at a certain depth below the surface, whether by the removal of matter by volcanos and hot springs, or by the contraction of argillaceous rocks by heat and pressure, or any other combination of circumstances. Whatever conjectures we may indulge respecting the causes, it is certain that pliable beds may, in consequence of unequal degrees of subsidence, become folded to any amount, and have all the appearance of having been compressed suddenly by a lateral thrust.

The "Creeps," as they are called in coal mines, afford an excellent illustration of this fact.—First, it may be stated generally, that the excavation of coal at a considerable depth causes the mass of overlying strata to sink down bodily, even when props are left to support the roof of the mine. "In Yorkshire," says Mr. Buddle, "three distinct subsidences were perceptible at the surface, after the clearing out of three seams of coal below, and

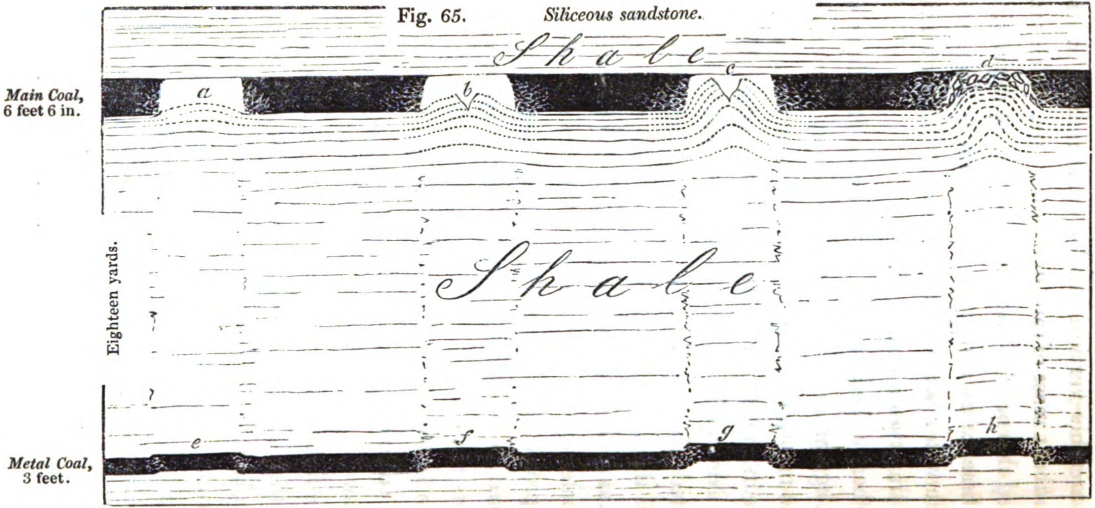
innumerable vertical cracks were caused in the incumbent mass of sandstone and shale, which thus settled down." * The exact amount of depression in these cases can only be accurately measured where water accumulates on the surface, or a railway traverses a coal-field.

When a bed of coal is worked out, pillars or rectangular masses of coal are left at intervals as props to support the roof, and protect the colliers. Thus in Fig. 65., representing a section at Wallsend, Newcastle, the galleries which have been excavated are represented by the white spaces *a b*, while the adjoining dark portions are parts of the original coal-seam left as props, beds of sandy clay or shale constituting the floor of the mine. When the props have been reduced in size, they are pressed down by the weight of overlying rocks no less than 630 feet thick, upon the shale below, which is thereby squeezed and forced up into the open spaces.

Now it might have been expected, that instead of the floor rising up, the ceiling would sink down, and this effect, called a "Thrust," does, in fact, take place where the pavement is more solid than the roof. But it usually happens, in coal-mines, that the roof is composed of sandstone or other materials more unyielding than the foundation, which often consists of clay or shale. Even where

* Proceedings of Geol. Soc. vol. iii. p. 148.

Fig. 65.



Section of carboniferous strata, at Walls-end, Newcastle, showing "Creeps." (J. Buddle, Esq.)
Horizontal length of section 174 feet. The upper seam, or main coal, here worked out, was 630 feet below the surface.

the argillaceous substrata are hard at first, they soon become softened and reduced to a plastic state when exposed to the contact of air and water in the floor of a mine.

The first symptom of a "creep," says Mr. Buddle, is a slight curvature at the bottom of each gallery, as at *a*, Fig. 65.: then the pavement continuing to rise, begins to open with a longitudinal crack, as at *b*: then the points of the fractured ridge reach the roof, as at *c*; and, lastly, the upraised beds close up the whole gallery, and the broken portions of the ridge are re-united and flattened at the top, exhibiting the flexure seen at *d*. Meanwhile the coal in the props has become crushed and cracked by pressure. It is also found, that below the creeps *a*, *b*, *c*, *d*, an inferior stratum, called the "metal coal," which is three feet thick, has been fractured at the points *e*, *f*, *g*, *h*, and has risen, so as to prove that the upward movement, caused by the working out of the "main coal," has been propagated through a thickness of 54 feet of argillaceous beds, which intervene between the two coal seams. This same displacement has also been traced downwards more than 150 feet below the metal coal, but it grows continually less and less until it becomes imperceptible.

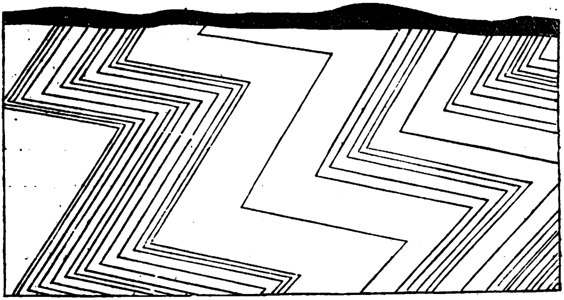
No part of the process above described is more deserving of our notice than the slowness with which the change in the arrangement of the beds

is brought about. Days, months, or even years, will sometimes elapse between the first bending of the pavement and the time of its reaching the roof. Where the movement has been most rapid, the curvature of the beds is most regular, and the reunion of the fractured ends most complete; whereas the signs of displacement or violence are greatest in those creeps which have required months or years for their entire accomplishment. Hence we may conclude that similar changes may have been wrought on a larger scale in the earth's crust by partial and gradual subsidences, especially where the ground has been undermined throughout long periods of time; and we must be on our guard against inferring sudden violence, simply because the distortion of the beds is excessive.

Between the layers of shale, accompanying coal, we sometimes see the leaves of fossil ferns spread out as regularly as dried plants between sheets of paper in the herbarium of a botanist. These fern-leaves, or fronds, must have rested horizontally on soft mud, when first deposited. If, therefore, they and the layers of shale are now inclined, or standing on end, it is obviously the effect of subsequent derangement. The proof becomes, if possible, still more striking when these strata, including vegetable remains, are curved again and again, and even folded into the form of the letter Z, so that the same continuous layer of coal is cut through several

times in the same perpendicular shaft. Thus, in the coal-field near Mons, in Belgium, these zigzag

Fig. 66.



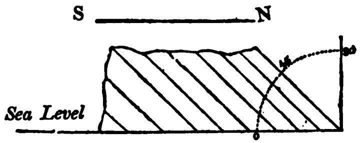
Zigzag flexures of coal near Mons.

bendings are repeated four or five times, in the manner represented in Fig. 66., the black lines representing seams of coal. *

Dip and Strike. — In the above remarks, several technical terms have been used, such as *dip*, the *unconformable position* of strata, and the *anticlinal* and *synclinal* lines, which, as well as the *strike* of the beds, I shall now explain. If a stratum or bed of rock, instead of being quite level, be inclined to one side, it is said to *dip;* the point of the compass to which it is inclined is called the *point of dip*, and the degree of deviation from a level or horizontal line is called *the amount of dip*,

* See plan by M. Chevalier, Burat's D'Aubuisson, tom. ii, p. 334.

Fig. 67.



or *the angle of dip.* Thus, in the annexed diagram (Fig. 67.), a series of strata are inclined, and they dip to the north at an angle of forty-five degrees. The *strike*, or *line of bearing*, is the prolongation or extension of the strata in a direction *at right angles* to the dip; and hence it is sometimes called the *direction* of the strata. Thus, in the above instance of strata dipping to the north, their strike must necessarily be east and west. We have borrowed the word from the German geologists, *streichen* signifying to extend, to have a certain direction. Dip and strike may be aptly illustrated by a row of houses running east and west, the long ridge of the roof representing the strike of the stratum of slates, which dip on one side to the north, and on the other to the south.

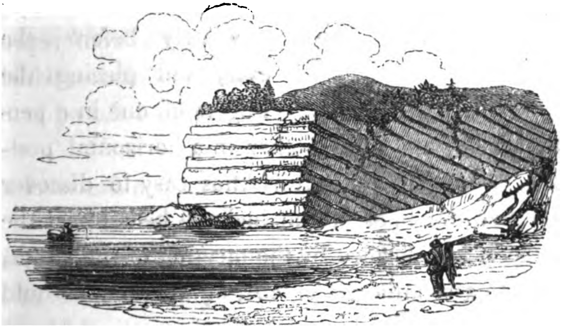
A stratum which is horizontal, or quite level in all directions, has neither dip nor strike.

It is always important for the geologist, who is endeavouring to comprehend the structure of a country, to learn how the beds dip in every part of the district; but it requires some practice to avoid being occasionally deceived, both as to the point of dip and the amount of it.

If the upper surface of a hard stony stratum be

uncovered, whether artificially in a quarry, or by the waves at the foot of a cliff, it is easy to determine towards what point of the compass the slope is steepest, or in what direction water would flow, if poured upon it. This is the true dip. But the edges of highly inclined strata may give rise to perfectly horizontal lines in the face of a vertical cliff, if the observer see the strata in the line of their strike, the dip being inwards from the face of the cliff. If, however, we come to a break in the cliff, which exhibits a section exactly at right angles to the line of the strike, we are then able to ascertain the true dip. In the annexed drawing (Fig. 68.), we may suppose a headland,

Fig. 68.



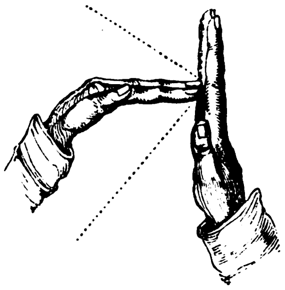
Apparent horizontality of inclined strata.

one side of which faces to the north, where the beds would appear perfectly horizontal, to a person in the boat; while in the other side facing the

west, the true dip would be seen by the person on shore to be at an angle of 40°. If, therefore, our observations are confined to a vertical precipice facing in one direction, we must endeavour to find a ledge or portion of the plane of one of the beds projecting beyond the others, in order to ascertain the true dip.

It is rarely important to determine the angle of inclination with such minuteness as to require the aid of the instrument called a clinometer. We

Fig. 69.



may measure the angle within a few degrees by standing exactly opposite to a cliff where the true dip is exhibited, holding the hands immediately before the eyes, and placing the fingers of one in a perpendicular, and of the other in a horizontal position, as in Fig. 69. It is thus easy to discover whether the lines of the inclined beds bisect the angle of 90°, formed by the meeting of the hands, so as to give an angle of 45°, or whether it would divide the space into two equal or unequal portions. The upper dotted line may express a stratum dipping to the north; but should the beds dip precisely to the opposite point of the compass as in the lower dotted line, it will be

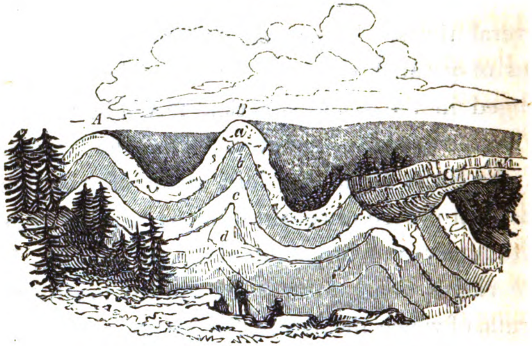
seen that the amount of inclination may still be measured by the hands with equal facility.

It has been already seen, in describing the curved strata on the east coast of Scotland, in Forfarshire and Berwickshire, that a series of concave and convex bendings are occasionally repeated several times. These usually form part of a series of parallel waves of strata, which are prolonged in the same direction throughout a considerable extent of country. Thus, for example, in the Swiss Jura, that lofty chain of mountains has been proved to consist of many parallel ridges, with intervening longitudinal valleys, as in Fig. 70., the ridges being formed by curved fossiliferous strata, of which the nature and dip are occasionally displayed in deep transverse gorges, called "cluses," caused by fractures at right angles to the direction of the chain.* Now let us suppose these ridges and parallel valleys to run north and south, we should then say that the *strike* of the beds is north and south, and the *dip* east and west. A line drawn along the summit of the ridges A, B would be an anticlinal line, and one following the bottom of the adjoining valleys a synclinal line. It will be observed that some of these ridges, A, B, are unbroken on the summit, whereas one of them,

* See M. Thurmann's work, "Essai sur les Soulèvemens Jurassiques du Porrentruy, Paris, 1832," with whom I examined part of these mountains in 1835.

C, has been fractured along the line of strike, and a portion of it carried away by denudation, so that the edges of the beds in the formations *a*, *b*, *c*, come out to the day, or, as the miners say,

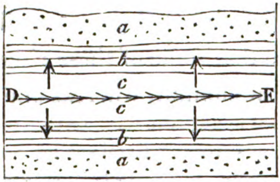
Fig. 70.

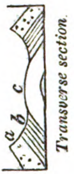


Section illustrating the structure of the Swiss Jura.

crop out, on the sides of a valley. The ground plan of such a denuded ridge as C, as given in a geological map, may be expressed by the diagram Fig. 71., and the cross section of the same by Fig. 72. The line D E, Fig. 71., is the anti-

Fig. 71. Fig. 72.





Ground plan of the denuded ridge C, fig. 70.

clinal line, on each side of which the dip is in opposite directions, as expressed by the arrows. The emergence of strata at the surface is called by miners their *outcrop* or *basset.*

If, instead of being folded into parallel ridges, the beds form a boss or dome-shaped protuberance, and if we suppose the summit of the dome carried off, the ground plan would exhibit the edges of the strata forming a succession of circles, or ellipses, round a common centre. These circles are the lines of strike, and the dip being always at right angles is inclined in the course of the circuit to every point of the compass, constituting what is termed a qua-qua-versal dip—that is, turning each way.

There are endless variations in the figures described by the basset-edges of the strata, according to the different inclination of the beds, and the mode in which they happen to have been denuded. One of the simplest rules with which every geologist should be acquainted, relates to the V-like form of the beds as they crop out in an ordinary valley. First, if the strata be horizontal, the V-like form will be also on a level, and the newest strata will appear at the greatest heights.

Secondly, if the beds be inclined and intersected by a valley sloping in the same direction, and the dip of the beds be less steep than the slope of the

valley, then the V's, as they are often termed by miners, will point upwards (see Fig. 73.), those formed by the newer beds appearing in a superior position, and extending highest up the valley, as A is seen above B.

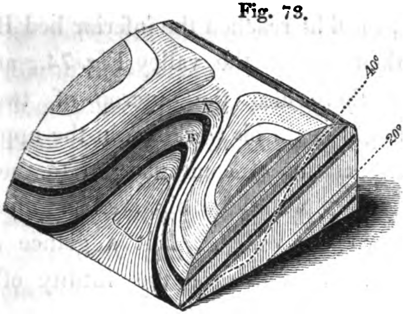
Thirdly, if the dip of the beds be steeper than the slope of the valley, then the V's will point downwards (see Fig. 74.), and those formed of the older beds will now appear uppermost, as B appears above A.

Fourthly, in every case where the strata dip in a contrary direction to the slope of the valley, whatever be the angle of inclination, the newer beds will appear the highest, as in the first and second cases. This is shown by the drawing (Fig. 75.), which exhibits strata rising at an angle of 20°, and crossed by a valley, which declines in an opposite direction at 20°.*

These rules may often be of great practical utility; for the different degrees of dip occurring in the two cases represented in figures 73. and 74. may occasionally be encountered in following the same line of flexure at points a few miles distant from each other. A miner unacquainted with the rule, who had first explored the valley (Fig. 73.), may have sunk a vertical shaft below the coal

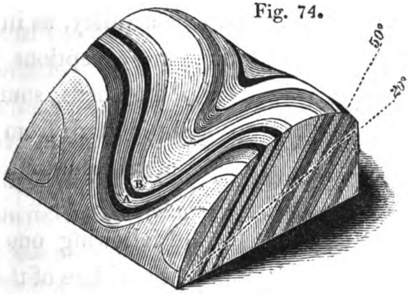
* I am indebted to the kindness of T. Sopwith, Esq., for three models constructed by him, which I have copied in the above diagrams.

Fig. 73.



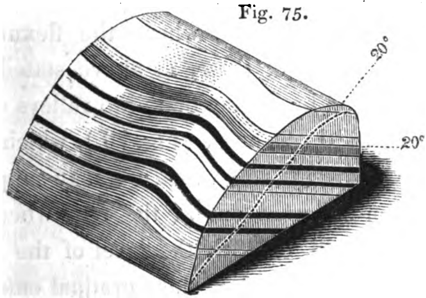
Slope of valley 40°, dip of strata 20°.

Fig. 74.



Slope of valley 20°, dip of strata 50°.

Fig. 75.

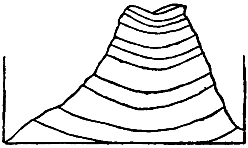


Slope of valley 20°, dip of strata 20°, in opposite directions.

seam A, until he reached the inferior bed B. He might then pass to the valley Fig. 74., and discovering there also the outcrop of two coal seams, might begin his workings in the uppermost in the expectation of coming down to the other bed A, which would be observed cropping out lower down the valley. But a glance at the section will demonstrate the futility of such hopes.

In the majority of cases, an anticlinal axis forms a ridge, and a synclinal axis a valley, as in A, B, Fig. 61. p. 103.; but there are exceptions to this rule, the beds sometimes sloping inwards from either side of a mountain, as in Fig. 76.

Fig. 76.

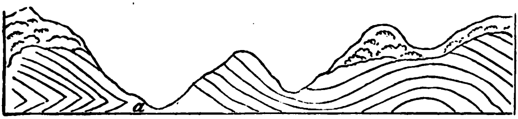


On following one of the anticlinal ridges of the Jura, before mentioned, A, B, C, Fig. 70., we often discover longitudinal cracks and sometimes large fissures along the line where the flexure was greatest. Some of these, as above stated, have been enlarged by denudation into valleys of considerable width, as at C. (Fig. 70.), which follow the line of strike, and which we may suppose to have been hollowed out at the time when these rocks were still beneath the level of the sea, or perhaps at the period of their gradual emergence from beneath the waters. The existence of such

cracks at the point of the sharpest bending of solid strata of limestone, such as that constituting the formation *a* (Fig. 70.), is precisely what we should have expected; but the occasional want of all similar signs of fracture, even where the strain has been equally great, is not always easy to explain. We must imagine that many strata of limestone, chert, and other rocks which are now brittle, were pliant when bent into their present position. They may have owed their flexibility in part to the fluids which they contained in their minute pores, as before described (p. 76.), and in part to the permeation of sea water while they were yet submerged.

At the western extremity of the Pyrenees, great curvatures of the strata are seen in the sea cliffs, where the rocks consist of marl, grit, and chert. At certain points, as at *a* (Fig. 77.), some of the

Fig. 77.



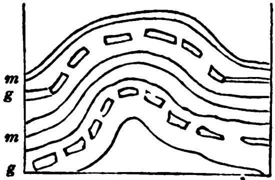
Strata of chert, grit, and marl, near St. Jean de Luz.

bendings of the flinty chert are so sharp, that specimens might be broken off, well fitted to serve as ridge-tiles on the roof of a house. Although this chert could not have been brittle as now,

when first folded into this shape, it presents, nevertheless, here and there at the points of greatest flexure small cracks, which show that it was solid, and not wholly incapable of breaking at the period of its displacement. The numerous rents alluded to are not empty, but filled with calcedony and quartz.

Between San Caterina and Castrogiovanni, in Sicily, bent and undulating gypseous marls occur, with here and there thin beds of solid gypsum interstratified. Sometimes these solid layers have been broken into detached fragments, still preserving their sharp edges, (*g g*, Fig. 78.), while the continuity of the more pliable and ductile marls, *m m*, has not been interrupted.

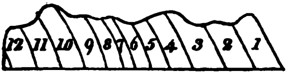
Fig. 78.



g. gypsum. *m*. marl.

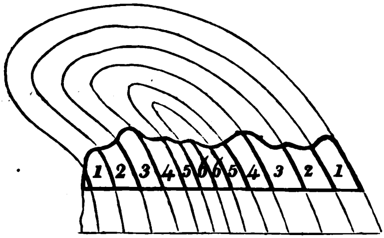
I shall conclude my remarks on bent strata by stating, that, in mountainous regions like the Alps, it is often difficult for an experienced geologist to determine correctly the relative age of beds by superposition, so often have the strata been folded back upon themselves, the upper parts of the curve having been removed by denudation. Thus, if we met with the strata seen in the section Fig. 79., we should naturally suppose that there were twelve distinct beds, or sets

Fig. 79.



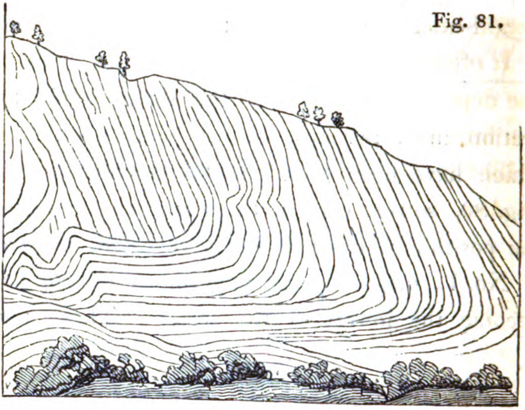
of beds, No. 1. being the youngest, and No. 12. the oldest of the series. But this section may, perhaps, exhibit merely six beds, which have been folded in the manner seen in Fig. 80., so that each of them are twice repeated, the position of one half being reversed, and part of No. 1., originally the uppermost, having now become the lowest of the series. These phe-

Fig. 80.



nomena are often observable on a magnificent scale in certain regions in Switzerland, where there are precipices from 2000 to 3000 feet in perpendicular height. In the Iselten Alp, in the valley of the Lutschine, between Unterseen and Grindelwald, curves of calcareous shale are seen from 1000 to 1500 feet in height, in which the beds sometimes plunge down vertically for a depth of 1000 feet and more, before they bend round again. There are many flexures not inferior in

Fig. 81.



Curved strata of the Iselten Alp.

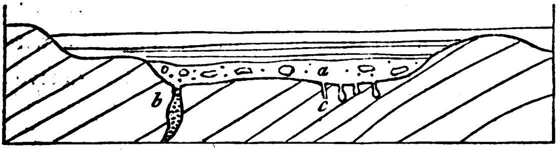
dimensions in the Pyrenees, as those near Gavarnie, at the base of Mont Perdu.

Unconformable stratification. — Strata are said to be unconformable, when one series is so placed over another, that the planes of the superior repose on the edges of the inferior (see Fig. 82.). In this case it is evident that a period had elapsed between the production of the two sets of strata, and that, during this interval, the inferior series had been tilted and disturbed. Afterwards the upper series was thrown down in horizontal strata upon it. If these superior beds are also inclined, it is plain that the lower strata have been twice displaced; first, when they were themselves brought into an inclined position, and a second time when

the superior beds were thrown out of the horizontal line.

It often happens that in the interval between the deposition of two sets of unconformable strata, the inferior rock has been denuded, and sometimes drilled by perforating shells. Thus, for example, at Autreppe and Gusigny, near Mons, beds of

Fig. 82.



Junction of unconformable strata near Mons, in Belgium.

ancient stone, commonly called transition limestone, highly inclined, and often bent, are covered with horizontal strata of greenish and whitish marls of the Cretaceous formation, which will be described in a future chapter. The lowest and therefore the oldest bed of the horizontal series is usually the sand and conglomerate, *a*, in which are rounded fragments of stone, from an inch to two feet in diameter. These fragments have often adhering shells attached to them, and have been bored by perforating mollusca. The solid surface of the inferior limestone has also been bored, so as to exhibit cylindrical and pear-shaped cavities, as at *c*, the work of saxicavous mollusca; and many rents, as at *b*, which descend

several feet or yards into the limestone, have been filled with sand and shells, similar to those in the stratum *a*.

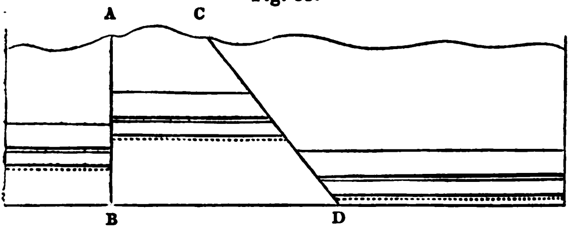
Fractures of the strata and faults.—Numerous rents may often be seen in rocks which appear to have been simply broken, the separated parts remaining in the same places; but we often find a fissure, several inches or yards wide, intervening between the disunited portions. These fissures are usually filled with fine earth and sand, or with angular fragments of stone, evidently derived from the fracture of the contiguous rocks.

The face of each wall of the fissure is often beautifully polished, as if glazed, and not unfrequently striated or scored with parallel furrows and ridges, such as would be produced by the continued rubbing together of surfaces of unequal hardness. These polished surfaces are called by miners "slickensides." It is supposed that the lines of the striæ indicate the direction in which the rocks were moved. During one of the late minor earthquakes in Chili, the brick walls of a building were rent vertically in several places, and made to vibrate for several minutes during each shock, after which they remained uninjured, and without any opening, although the line of each crack was still visible. When all movement had ceased, there were seen on the floor of the house, at the bottom of each rent, small heaps

of fine brickdust, evidently produced by trituration.

It is not uncommon to find the mass of rock, on one side of a fissure, thrown up above or down below the mass with which it was once in contact on the other side. This mode of displacement is called a shift, slip, or fault. "The miner," says Playfair, describing a fault, "is often perplexed, in his subterraneous journey, by a derangement in the strata, which changes at once all those lines and bearings which had hitherto directed his course. When his mine reaches a certain plane, which is sometimes perpendicular, as in A B, Fig. 83., sometimes oblique to the horizon (as in C D, ibid.), he finds the beds of rock broken asunder, those on the one side of the

Fig. 83.

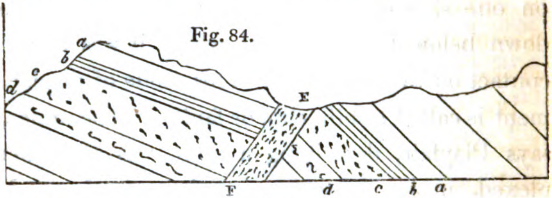


Faults. A B *perpendicular*, C D *oblique to the horizon.*

plane having changed their place, by sliding in a particular direction along the face of the others. In this motion they have sometimes preserved their parallelism, as in Fig. 83., so that the strata on each side of the faults A B, C D, con-

tinue parallel to one another; in other cases, the strata on each side are inclined, as in *a, b, c, d,* (Fig. 84.), though their identity is still to be re-

Fig. 84.



E F, *fault or fissure filled with rubbish, on each side of which the shifted strata are not parallel.*

cognized by their possessing the same thickness, and the same internal characters." *

In Coalbrook Dale, says Mr. Prestwich †, deposits of sandstone, shale, and coal, several thousand feet thick, and occupying an area of many miles, have been shivered into fragments, and the broken remnants have been placed in very discordant positions, often at levels differing several hundred feet from each other. The sides of the faults, when perpendicular, are commonly separated several yards, but are sometimes as much as 50 yards asunder, the interval being filled with broken *débris* of the strata. In following the course of the same fault it is sometimes found to produce in different places very unequal changes of level, the amount of shift being in one

* Playfair, Illust. of Hutt. Theory, § 42.

† Geol. Trans. second series, vol. v. p. 452.

place 300, and in another 700 feet, which arises, in some cases, from the union of two or more faults. In other words, the disjointed strata have in certain districts been subjected to renewed movements, which they have not suffered elsewhere.

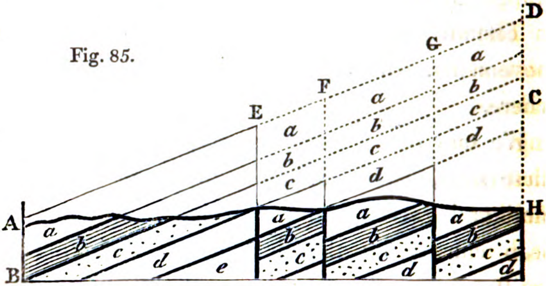
We may occasionally see exact counterparts of these slips, on a small scale, in pits of fine loose sand and gravel, many of which have doubtless been caused by the drying and shrinking of argillaceous and other beds, slight subsidences having taken place from failure of support. Sometimes, however, even these small slips may have been produced during earthquakes; for land has been moved, and its level, relatively to the sea, considerably altered, within the period when much of the alluvial sand and gravel now covering the surface of continents was deposited.

I have already stated that a geologist must be on his guard, in a region of disturbed strata, against inferring repeated alternations of rocks, when, in fact, the same strata, once continuous, have been bent round so as to recur in the same section, and with the same dip. A similar mistake has often been occasioned by a series of faults.

If, for example, the dark line A H (Fig. 85.) represent the surface of a country on which the strata *a b c* frequently crop out, an observer, who is proceeding from H to A, might at first imagine

that at every step he was approaching new strata, whereas the repetition of the same beds has been

Fig. 85.



Apparent alternations of strata caused by vertical faults.

caused by vertical faults, or downthrows. Thus, suppose the original mass, A, B, C, D, to have been a set of uniformly inclined strata, and that the different masses under E F, F G, and G D, sank down successively, so as to leave vacant the spaces marked in the diagram by dotted lines, and to occupy those marked by the continuous lines, then let denudation take place along the line A H, so that the protruding and triangular masses indicated by the fainter lines are swept away,—a miner, who has not discovered the faults, finding the mass *a*, which we will suppose to be a bed of coal four times repeated, might hope to find four beds, workable to an indefinite depth, but first on arriving at the fault G he is stopped suddenly in his workings, upon reaching the strata of sandstone *c*, or on arriving at the line of fault

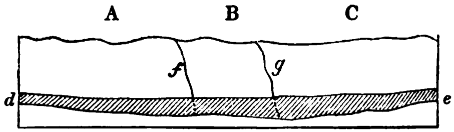
F he comes partly upon the shale *b*, and partly on the sandstone *c*, and on reaching E he is again stopped by a wall composed of the rock *d*.

The very different levels at which the separated parts of the same strata are found on the different sides of the fissure, in some faults, is truly astonishing. One of the most celebrated in England is that called the "ninety-fathom dike," in the coal-field of Newcastle. This name has been given to it, because the same beds are ninety fathoms lower on the northern than they are on the southern side. The fissure has been filled by a body of sand, which is now in the state of sandstone, and is called the dike, which is sometimes very narrow, but in other places more than twenty yards wide.* The walls of the fissure are scored by grooves, such as would have been produced if the broken ends of the rock had been rubbed along the plane of the fault.† In the Tynedale and Craven faults, in the north of England, the vertical displacement is still greater, and has extended in a horizontal direction for a distance of thirty miles or more. Some geologists consider it necessary to imagine that the upward or downward movement in these cases was accomplished at a single stroke, and not by a series of sudden but interrupted movements.

* Conybeare and Phillips, Outlines, &c. p. 376.
† Phillips, Geology, Lardner's Cyclop. p. 41.

This idea appears to have been derived from a notion that the grooved walls have merely been rubbed in one direction. But this is so far from being a constant phenomenon in faults, that it has often been objected to the received theory respecting those polished surfaces called "slickensides," that the striæ are not always parallel, but often curved and irregular. It has, moreover, been remarked, that not only the walls of the fissure or fault, but its earthy contents, sometimes present the same polished and striated faces. Now these facts seem to indicate partial changes in the direction of the movement, and some slidings subsequent to the first filling up of the fissure. Suppose the mass of rock A, B, C, to overlie an extensive chasm *d e*, formed at the depth

Fig. 86.



of several miles, whether by the gradual contraction in bulk of a mass of strata, baked by a moderate heat, or by the subtraction of matter by volcanic action, or any other cause. Now, if this region be convulsed by earthquakes, the fissures *f g*, and others at right angles to them, may sever the mass B from A and from C, so that it may move freely,

and begin to sink into the chasm. A fracture may be conceived so clean and perfect as to allow it to subside at once to the bottom of the subterranean cavity; but it is far more probable that the sinking will be effected at successive periods during different earthquakes, the mass always continuing to slide in the same direction along the planes of the fissures *f g*, and the edges of the falling mass being continually more broken and triturated at each convulsion. If, as is not improbable, the circumstances which have caused the failure of support continue in operation, it may happen that when the mass B has filled the cavity first formed, its foundations will again give way under it, so that it will fall again in the same direction. But, if the direction should change, the fact could not be discovered by observing the slickensides, because the last scoring would efface the lines of previous friction. In the present state of our ignorance of the causes of subsidence, an hypothesis which can explain the great amount of displacement in some faults, on sound mechanical principles, by a succession of movements, is far preferable to any theory which assumes each fault to have been accomplished by a single upcast or downthrow of several thousand feet. For we know that there are operations now in progress, at great depths in the interior of the earth, by which both large and small tracts of ground are made to rise above

and sink below their former level, some slowly and insensibly, others suddenly and by starts, a few feet or yards at a time; whereas there are no grounds for believing that, during the last 3000 years at least, any regions have been either upheaved or depressed, at a single stroke, to the amount of several hundred, much less several thousand feet.

CHAPTER VI.

DENUDATION.

Denudation defined — Its amount equal to the entire mass of stratified deposits in the earth's crust — Horizontal sandstone denuded in Ross-shire — Levelled surface of countries in which great faults occur — Coalbrook Dale — Denuding power of the ocean during the emergence of land — Origin of valleys — Inland sea-cliffs and terraces in the Morea and Sicily — Limestone pillars at St. Mihiel, in France — in Canada — in the Bermudas — Obliteration of cliffs.

Denudation, which has been occasionally spoken of in the preceding chapters, is the removal of solid matter by running water, whether by a river or marine current, and the consequent laying bare of some inferior rock. Geologists have perhaps been seldom in the habit of reflecting that this operation has exerted an influence on the structure of the earth's crust as universal and important as sedimentary deposition itself; for denudation is the inseparable accompaniment of the production of all new strata of mechanical origin. The formation of every new deposit by the transport of sediment and pebbles necessarily implies that there has been, somewhere else, a

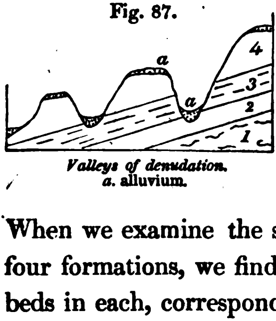
grinding down of rock into rounded fragments, sand, or mud, equal in quantity to the new strata. All deposition, therefore, except in the case of a shower of volcanic ashes, is the sign of superficial waste going on contemporaneously, and to an equal amount elsewhere. The gain at one point is no more than sufficient to balance the loss at some other. Here a lake has grown shallower, there a ravine has been deepened. The bed of the sea has in one region been raised by the accumulation of new matter, in another its depth has been augmented by the abstraction of an equal quantity.

When we see a stone building, we know that somewhere, far or near, a quarry has been opened. The courses of stone in the building may be compared to successive strata, the quarry to a ravine or valley which has suffered denudation. As the strata, like the courses of hewn stone, have been laid one upon another gradually, so the excavation both of the valley and quarry have been gradual. To pursue the comparison still farther, the superficial heaps of mud, sand, and gravel usually called alluvium, may be likened to the rubbish of a quarry which has been rejected as useless by the workmen, or has fallen upon the road between the quarry and the building, so as to lie scattered at random over the ground.

If, then, the entire mass of stratified deposits in

the earth's crust is at once the monument and measure of the denudation which has taken place, on how stupendous a scale ought we to find the signs of this removal of transported materials in past ages! Accordingly, there are different classes of phenomena, which attest in a most striking manner the vast spaces left vacant by the erosive power of water. I may allude, first, to those valleys on both sides of which the same strata are seen following each other in the same order, and having the same mineral composition and fossil contents. We may observe, for example, several formations, as Nos. 1, 2, 3, 4, in the accompanying diagram (Fig. 87.); No. 1. conglomerate, No. 2. clay, No. 3. grit, and No. 4. limestone, each repeated in a series of hills separated by valleys varying in depth.

Fig. 87.

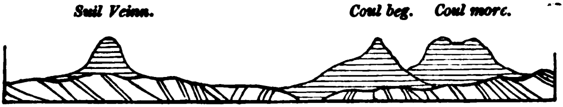


Valleys of denudation.
a. alluvium.

When we examine the subordinate parts of these four formations, we find, in like manner, distinct beds in each, corresponding, on the opposite sides of the valleys, both in composition and order of position. No one can doubt that the strata were originally continuous, and that some cause has swept away the portions which once connected the whole series. A torrent on the side of a mountain produces similar interruptions; and when we make artificial cuts in lowering roads, we expose, in like

manner, corresponding beds on either side. But in nature, these appearances occur in mountains several thousand feet high, and separated by intervals of many miles or leagues in extent, of which a grand exemplification is described by Dr. MacCulloch, on the north-western coast of Ross-shire, in Scotland.*

Fig. 88.



Denudation of red sandstone on north-west coast of Ross-shire. (MacCulloch.)

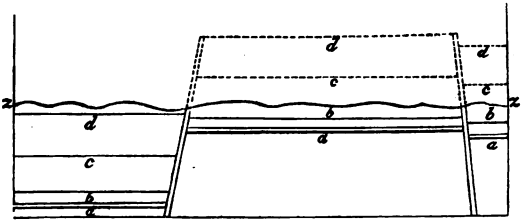
The fundamental rock of that country is gneiss, in disturbed strata, on which beds of nearly horizontal red sandstone rest unconformably. The latter are often very thin, forming mere flags, with their surface distinctly ripple-marked. They end abruptly on the declivities of many insulated mountains, which rise up at once to the height of about 2000 feet above the gneiss of the surrounding plain or table land, and to an average elevation of about 3000 feet above the sea, which all their summits generally attain. The base of gneiss varies in height, so that the lower portions of the sandstone occupy different levels, and the thickness of the mass is various, sometimes exceeding 3000 feet. It is impossible to compare these

* Western Islands, vol. ii. p. 93. pl. 31. fig. 4.

scattered and detached portions without imagining that the whole country has once been covered with a great body of sandstone, and that masses from 1000 to more than 3000 feet in thickness have been removed.

But perhaps the most convincing evidence of denudation on a magnificent scale is derived from the levelled surface of many districts, in which large faults occur. I have already shown, in Fig. 85. p. 132., and in Fig. 89., how angular and protruding masses of rock might naturally have been looked for on the surface immediately above great faults, although in fact they rarely exist. This phenomenon may be well studied in those districts where coal has been extensively worked, for there the former relation of the beds which have shifted their position may be determined with great accuracy. Thus in the coal field of Ashby de la

Fig. 89.



Faults and denuded coal strata, Ashby de la Zouch. (Mammat.)

Zouch, in Leicestershire (see Fig. 89.), a fault occurs, on one side of which the coal beds *a b c d*

rise to the height of 500 feet above the corresponding beds on the other side. But the uplifted strata do not stand up 500 feet above the general surface; on the contrary, the outline of the country, as expressed by the line *z z*, is uniform and unbroken, and the mass indicated by the dotted outline must have been washed away.* There are proofs of this kind in some level countries, where dense masses of strata have been cleared away from areas several hundred square miles in extent.

In the Newcastle coal district it is ascertained that faults occur in which the upward or downward movement could not have been less than 140 fathoms, which, had they affected equally the configuration of the surface to that amount, would produce mountains with precipitous escarpments nearly 1000 feet high, or chasms of the like depth; yet is the actual level of the country absolutely uniform, affording no trace whatever of subterranean movements.†

The ground from which these materials have been removed is usually overspread with heaps of sand and gravel, formed out of the ruins of the very rocks which have disappeared. Thus, in the districts above referred to, they consist of rounded and angular fragments of hard sandstone, lime-

* See Mammat's Geological Facts, &c. p. 90. and plate.

† Conybeare's Report to Brit. Assoc. 1832, p. 381.

stone, and ironstone, with a small quantity of the more destructible shale, and even rounded pieces of coal.

Allusion has been already made to the shattered state and discordant position of the carboniferous strata in Coalbrook Dale (p. 130.). The collier cannot proceed three or four yards without meeting with small slips, and from time to time he encounters faults of considerable magnitude, which have thrown the rocks up or down several hundred feet. Yet the superficial inequalities to which these dislocated masses originally gave rise are no longer discernible, and the comparative flatness of the existing surface can only be explained, as Mr. Prestwich has observed, by supposing the fractured portions to have been removed by water. It is also clear that strata of red sandstone, more than 1000 feet thick, which once covered the coal, in the same region, have been carried away from large areas. That water has, in this case, been the denuding agent, we may infer from the fact, that the rocks have yielded according to their different degrees of hardness; the hard trap of the Wrekin, for example, and other hills, having resisted more than the softer shale and sandstone, so as now to stand out in bold relief.*

Origin of valleys.— It is very generally admit-

* Prestwich, Geol. Trans. second series, vol. v. pp. 452. 473.

ted, that the greater number of valleys are chiefly or entirely due to the excavating power of water, but many different theories have been entertained respecting the manner in which the force of moving water has been brought to bear upon the land. Some geologists, being at a loss to conceive any combination of known causes capable of giving rise to effects of such magnitude, have imagined a deluge, or succession of deluges, caused by the sudden upheaval of mountain chains, to have rolled with resistless violence over the land, after it had acquired its present elevation above the sea. But many gratuitous assumptions are involved in this hypothesis; and even if we were disposed to grant the instantaneous upthrow from the ocean of lofty chains, and a series of enormous waves as a consequence of each convulsion, we can by no means account for the observed phenomena. On the other hand, it has now been ascertained, that the rising and sinking of extensive portions of the earth's crust, whether insensibly or by a repetition of sudden shocks, is part of the actual course of nature, and we may easily comprehend how the land may have been exposed during these movements to abrasion by the waves of the sea. In the same manner as a mountain mass may (in the course of ages) be formed by sedimentary deposition, layer after layer, so masses equally voluminous may in time waste away by

inches, as for example, if beds of incoherent materials are raised slowly in an open sea where a strong current prevails. It is well known that some of these oceanic currents have a breadth of 200 miles, and that they sometimes run for a thousand miles or more in one direction, retaining a considerable velocity even at the depth of several hundred feet. Under these circumstances, the flowing waters may have power to clear away each stratum of incoherent materials as it rises and approaches the surface, where the waves exert the greatest force; and in this manner a voluminous deposit may be entirely swept away, so that, in the absence of faults, no evidence may remain of the denuding operation. It is clear, therefore, that the signs of waste will usually be least obvious where the destruction has been most complete, the annihilation having proceeded so far, that no ruins are left of the dilapidated rocks: nevertheless, we may always appeal to one striking proof of the vast extent of denudation in times past, namely, the existence before alluded to in all parts of the earth's crust of strata of mechanical origin, many thousand feet thick (see page 137.).

In regard to valleys, it may be observed, that denudation, which has often had a levelling influence on countries of shattered and disturbed strata, (see Fig. 85. p. 132. and Fig. 89. p. 141.) is the chief cause of superficial inequalities in regions

of horizontal stratification. The general outline of these regions is that of flat and level platforms, interrupted by valleys often of considerable depth, and ramifying in various directions. These dry hollows may once have formed bays and channels between islands, and the steepest slope on the sides of each valley may have been a sea-cliff, which was undermined for ages, as the land emerged gradually from the deep. We may suppose the position and course of each valley to have been originally determined by differences in the hardness of the rocks, and by rents and joints which usually occur even in horizontal strata. In mountain chains, such as the Jura before described, (see Fig. 70. p. 118.) we perceive at once that the principal valleys have not been due to aqueous excavation, but to those mechanical movements which have bent the rocks into their present form. Yet even in the Jura there are many valleys, such as C, (Fig. 70.) which have been hollowed out by water; and it may be stated, that in every part of the globe the unevenness of the surface of the land has been due to the combined influence of subterranean movements and denudation.

I may now recapitulate a few of the conclusions to which we have arrived: first, all the mechanical strata have been accumulated gradually, and the concomitant denudation has been no less gradual: secondly, the dry land consists in great part of

strata formed originally at the bottom of the sea, and has been made to emerge and attain its present height by a force acting from beneath: thirdly, no combination of causes has yet been conceived so capable of producing extensive and gradual denudation, as the action of the waves and currents of the ocean upon land slowly rising out of the deep.

Now, if we embrace these conclusions, we shall naturally be led to look every where for marks of the former residence of the sea upon the land, especially near the coasts from which the last retreat of the waters took place, and it will be found that such signs are not wanting. Thus, in the Morea, no less than three, or even four, ranges of what were once sea-cliffs are well preserved. These have been described, by MM. Boblaye and Virlet, as rising one above the other at different distances from the actual shore, the summit of the highest and oldest occasionally exceeding 1000 feet in elevation. At the base of each there is usually a terrace, which is in some places a few yards, in others above 300 yards wide, so that we are conducted from the high land of the interior to the sea by a succession of great steps. These inland cliffs are most perfect, and most exactly resemble those now washed by the waves of the Mediterranean, where they are formed of calcareous rock, especially if the rock be a hard

crystalline marble. The following are the points of correspondence observed between the ancient coast lines and the borders of the present sea:— 1. A range of vertical precipices, with a terrace at their base. 2. A weathered state of the surface of the naked rock, such as the spray of the sea produces. 3. A line of littoral caverns at the foot of the cliffs. 4. A consolidated beach or breccia with occasional marine shells, found at the base of the cliffs, or in the caves. 5. Lithodomous perforations.

In regard to the first of these, it would be superfluous to dwell on the evidence afforded of the undermining power of waves and currents by perpendicular precipices. The littoral caves, also, will be familiar to those who have had opportunities of observing the manner in which the waves of the sea, when they beat against rocks, have power to scoop out caverns. As to the breccia, it is composed of pieces of limestone and rolled fragments of thick solid shells, such as *Strombus* and *Spondylus*, all bound together by a crystalline calcareous cement. Similar aggregations are now forming on the modern beaches of Greece, and in caverns on the sea-side; and they are only distinguishable in character from those of more ancient date, by including many pieces of pottery. In regard to the *lithodomi* above alluded to, these bivalve mollusks are well known to

have the power of excavating holes in the hardest limestones, the size of the cavity keeping pace with the growth of the shell. When living they require to be always covered by salt water, but similar pear-shaped hollows, containing the dead shells of these creatures, are found at different heights on the face of the inland cliffs above mentioned. Thus, for example, they have been observed near Modon and Navarino on cliffs in the interior 125 feet high above the Mediterranean. As to the weathered surface of the calcareous rocks, all limestones are known to suffer chemical decomposition when moistened by the spray of the salt water, and are corroded still more deeply at points lower down where they are just reached by the breakers. By this action the stone acquires a wrinkled and furrowed outline, and very near the sea it becomes rough and branching, as if covered with corals. Such effects are traced not only on the present shore but at the base of the ancient cliffs far in the interior. Lastly, it remains only to speak of the terraces, which extend with a gentle slope from the base of almost all the inland cliffs and are for the most part narrow where the rock is hard, but sometimes half a mile or more in breadth where it is soft. They are the effects of the encroachment of the ancient sea upon the shore at those levels at which the land remained for a long time

stationary. The justness of this view is apparent on examining the shape of the modern shore wherever the sea is advancing upon the land, and removing annually small portions of undermined rock. By this agency a submarine platform is produced on which we may walk for some distance from the beach in shallow water, the increase of depth being very gradual, until we reach a point where the bottom plunges down suddenly. This platform is widened with more or less rapidity according to the hardness of the rocks, and when upraised it constitutes an inland terrace.

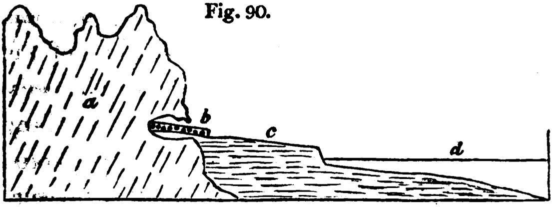
But the four principal lines of cliff observed in the Morea do not imply, as some have imagined, four great eras of sudden upheaval; they simply indicate the intermittance of the upheaving force. Had the rise of the land been continuous and uninterrupted, there would have been no one prominent line of cliff; for every portion of the surface having been, in its turn, and for an equal period of time, a sea-shore, would have presented a nearly similar aspect. But if pauses occur in the process of upheaval, the waves and currents have time to sap, throw down, and clear away considerable masses of rock, and to shape out at certain levels lofty ranges of cliffs with broad terraces at their base.

There are some levelled spaces, however, both

ancient and modern, in the Morea, which are not due to denudation, although resembling in outline the terraces above described. They may be called Terraces of Deposition, since they have resulted from the gain of land upon the sea where rivers and torrents have produced deltas. If the sedimentary matter has filled up a bay or gulf surrounded by steep mountains, a flat plain is formed skirting the inland precipices; and if these deposits are upraised, they form a feature in the landscape very similar to the areas of denudation before described.

In the island of Sicily are many inland cliffs like those of the Morea; as for example, near Palermo, where a precipice is seen consisting of limestone at the base of which are numerous caves.

Fig. 90.



a. Monte Grifone. *b.* Cave of San Ciro.*
c. Plain of Palermo, in which are Newer Pliocene strata of limestone and sand. *d.* Bay of Palermo.

* Section given by Dr. Christie, Edin. New Phil. Journ. No. xxiii., called by mistake the Cave of Mardolce, by the late M. Hoffmann. See account by Mr. S. P. Pratt, F.G.S. Proceedings of Geol. Soc. No. 32. 1833.

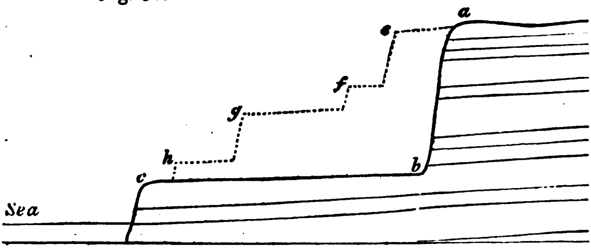
One of these called San Ciro, about 2 miles distant from Palermo, is about 20 feet high, 10 wide, and 180 above the sea. Within it is found an ancient beach (*b.* Fig. 90.), formed of pebbles of various rocks, many of which must have come from places far remote. Broken pieces of coral and shell, especially of oysters and pectens, are seen intermingled with the pebbles. Immediately above the level of this beach, *serpulæ* are still found adhering to the face of the rock, and the limestone is perforated by *lithodomi*. Within the grotto, also, at the same level, similar perforations occur; and so numerous are the holes, that the rock is compared by Hoffmann to a target pierced by musket balls. But in order to expose to view these marks of boring-shells in the interior of the cave, it was necessary first to remove a mass of breccia, which consisted of numerous fragments of rock and an immense quantity of bones of the mammoth, hippopotamus, and other quadrupeds, imbedded in a dark brown calcareous marl. Many of the bones were rolled as if partially subjected to the action of the waves. Below this breccia, which is about twenty feet thick, was found a bed of sand filled with sea-shells of recent species; and underneath the sand, again, is the secondary limestone of Monte Grifone. The state of the surface of the limestone in the cave above the level of the marine sand is very different from that

below it. *Above,* the rock is jagged and uneven, as is usual in the roofs and sides of limestone caverns; *below,* the surface is smooth and polished, as if by the attrition of the waves.

The platform indicated at *c*, Fig. 90., is formed by a tertiary deposit containing marine shells almost all of living species, and it affords an illustration of the terrace of deposition, or the last of the two kinds before mentioned (p. 151.).

There are also numerous instances in Sicily of terraces of denudation. One of these occurs on the east coast to the north of Syracuse, and the same is resumed to the south beyond the town of Noto, where it forms a continuous and lofty precipice *a*, *b*, facing towards the sea, and constituting the abrupt termination of a calcareous formation, which extends in horizontal strata far inland. This precipice varies in height from 500 to 700 feet,

Fig. 91.



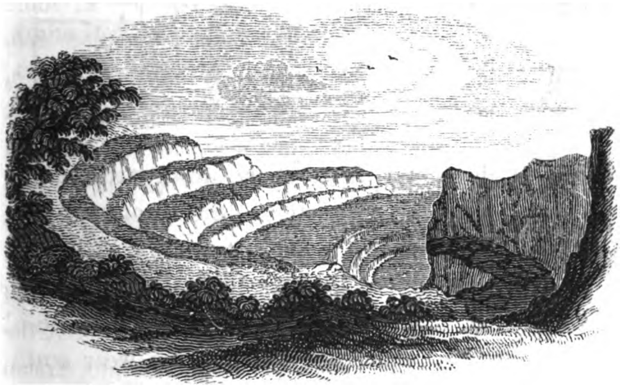
and between its base and the sea is an inferior platform *c*, *b*, consisting of similar white limestone. All the beds dip towards the sea, but are usually

inclined at a very slight angle: they are seen to extend uninterruptedly from the base of the escarpment into the platform, showing distinctly that the lofty cliff was not produced by a fault or vertical shift of the beds, but by the removal of a considerable mass of rock. Hence we may conclude that the sea, which is now undermining the cliffs of the Sicilian coast, reached at some former period the base of the precipice *a*, *b*, at which time the surface of the terrace *c*, *b*, must have been covered by the Mediterranean. There was a pause, therefore, in the upward movement, when the waves of the sea had time to carve out the platform *c*, *b*; but there may have been many other stationary periods of minor duration. Suppose, for example, that a series of escarpments *e*, *f*, *g*, *h*, once existed, and that the sea, during a long interval free from subterranean movements, advances along the line *c*, *b*, all preceding cliffs must have been swept away one after the other, and reduced to the single precipice *a*, *b*.

That such a series of smaller cliffs, as those represented at *e*, *f*, *g*, *h*, Fig. 91., did really once exist at intermediate heights in place of the single precipice *a*, *b*, is rendered highly probable by the fact, that in certain bays and inland valleys opening towards the east coast of Sicily, and not far from the section given in Fig. 91., the solid

limestone is shaped out into a great succession of ledges, separated from each other by small vertical cliffs. These are sometimes so numerous, one above the other, that where there is a bend at the head of a valley, they produce an effect singularly resembling the seats of a Roman amphitheatre.

Fig. 92.



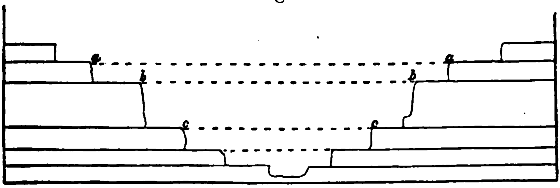
Valley called Gozzo degli Martiri, below Melilli, Val di Noto.

A good example of this configuration occurs near the town of Melilli, as seen in the annexed view (Fig. 92.). In the south of the island, near Spaccaforno, Scicli, and Modica, precipitous rocks of white limestone, ascending to the height of 500 feet, have been carved out into similar forms.

This appearance of a range of marble seats circling round the head of a valley, or of great flights of steps descending from the top to the

bottom, on the opposite sides of a gorge, may be accounted for, as already hinted, by supposing the sea to have stood successively at many different levels, as at *a, a, b, b, c, c,* in the accompanying fig. 93. But the causes of the gradual contrac-

Fig. 93.



tion of the valley from above downwards may still be matter of speculation. Such contraction may be due to the greater force exerted by the waves when the land at its first emergence was smaller in quantity, and more exposed to denudation in an open sea; whereas the wear and tear of the rocks might diminish in proportion as this action became confined within bays or channels closed in on two or three sides. Or, secondly, the separate movements of elevation may have followed each other more rapidly as the land continued to rise, so that the times of those pauses, during which the greatest denudation was accomplished at certain levels, were always growing shorter. It should be remarked, that the cliffs and small terraces are rarely found on the opposite sides of the Sicilian valleys at heights so precisely

answering to each other as those given in Fig. 93., and this might have been expected, to whichever of the two hypotheses above explained we incline; for, according to the direction of the prevailing winds and currents, the waves may beat with unequal force on different parts of the shore, so that while no impression is made on one side of a bay, the sea may encroach so far on the other as to unite several smaller cliffs into one.

Before quitting the subject of ancient sea cliffs, carved out of limestone, I shall mention the range of precipitous rocks, composed of a white marble of the Oolitic period, which may be seen near the northern gate of St. Mihiel in France. They are situated on the right bank of the Meuse, at a distance of 200 miles from the nearest sea, and they present on the precipice facing the river three or four horizontal grooves, one above the other, precisely resembling those which are scooped out by the undermining waves. The summits of several of these masses are detached from the adjoining hill, in which case the grooves pass all round them, facing towards all points of the compass, as if they had once formed rocky islets near the shore.*

Captain Bayfield, in his survey of the Gulf of

* I was directed by M. Deshayes to this spot, which I visited in June, 1833.

St. Lawrence, discovered in several places, especially in the Mingan islands, a counterpart of the inland cliffs of St. Mihiel, and traced a succession of shingle beaches, one above the other, which agreed in their level with some of the principal grooves scooped out of the limestone pillars. These beaches consisted of calcareous shingle, with shells of recent species, the farthest from the shore being sixty feet above the level of the highest tides. In addition to the drawings of the pillars called the flower-pots, which he has

Fig. 94.

Limestone columns in Niapisca Island, in the Gulf of St. Lawrence. Height of the second column on the left, 60 *feet.*

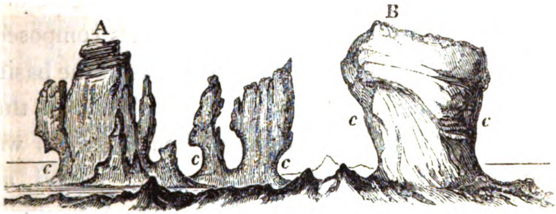
published *, I have been favoured with other views of rocks on the same coast, drawn by Lieut. A. Bowen, R. N. (See Fig. 94.)

* See Trans. of Geol. Soc., second series, vol. v. plate v.

In the North-American beaches above mentioned rounded fragments of limestone have been found perforated by *lithodomi;* and holes drilled by the same mollusks have been detected in the columnar rocks or "flower-pots," showing that there has been no great amount of atmospheric decomposition on the surface, or the cavities alluded to would have disappeared.

We have an opportunity of seeing in the Bermuda islands the manner in which the waves of the Atlantic have worn, and are now wearing out, deep smooth hollows on every side of projecting masses of hard limestone. In the an-

Fig. 95.



The North Rocks, Bermuda, lying outside the great coral reef.
A. 16 feet high, and B. 12 feet. *c. c.* Hollows worn by the sea.

nexed drawing, communicated to me by Lieut. Nelson, the excavations *c, c, c,* have been scooped out by the waves in a stone of very modern date, which, although extremely hard, is full of recent corals and shells, some of which retain their colour.

When the forms of these horizontal grooves, of

which the surface is sometimes smooth and almost polished, and the roofs of which often overhang to the extent of five feet or more, have been carefully studied by geologists, they will serve to testify the former action of the waves at innumerable points far in the interior of the continents. But we must learn to distinguish the indentations due to the original action of the sea, and those caused by subsequent chemical decomposition of calcareous rocks, to which they are liable in the atmosphere.

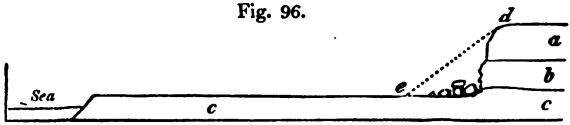
It may be asked why, if the doctrines above expounded are true, there are not inland cliffs and sea-beaches every where? whereas, even in Sicily and the Morea they are partial, and are entirely wanting in many large districts composed of argillaceous and sandy formations, as in the basin of the Thames, for example. This absence is the more striking in the Morea and Sicily, when we reflect on the comparatively recent period at which large parts of those countries have emerged from the deep. The modern date of that event is shown either by shells of recent species found in raised beaches, or imbedded in calcareous and argillaceous formations Yet, notwithstanding the comparative shortness of the time since these strata emerged from the deep, and the fresh aspect of some of the inland cliffs above described, it is difficult, in general, when we pass beyond the

limits of the solid limestone, to detect any signs of the beating of the waves on ancient shores. That the soft marly and sandy strata were upheaved at the same time, and by the same intermittent movements as the adjoining calcareous rocks, cannot be doubted. To understand in such cases the rarity of the traces of ancient shores, we must observe how soon all recent marks of the same kind are obscured or entirely effaced on any point of our own coast, where, in consequence of the altered state of the tides and currents, the sea has receded for a few centuries. We see the cliffs crumble down in a few years, and if they have consisted of sand or clay, they are soon reduced to a gentle slope. If there were shells on the beach they decompose, and their materials are soon washed away, after which the sand and shingle may resemble any other alluviums scattered over the interior.

The features of an ancient shore may be concealed by the growth of trees and shrubs, or by a covering of blown sand, a good example of which occurs a few miles west from Dax, near Bourdeaux, in the South of France. About twelve miles inland, a steep bank may be traced running in a direction nearly north-east and south-west, or parallel to the contiguous coast. This sudden fall of about fifty feet conducts us from the higher platform of the Landes to a lower plain which

extends to the sea. The outline of the ground might suggest to every geologist the opinion

Fig. 96.



Section of Inland Cliff at Abesse, near Dax.
a. Sand of the Landes. *b.* Limestone. *c.* Clay.

that the bank in question was once a sea-cliff, when the whole country stood at a lower level. But this can no longer be regarded as matter of conjecture. In making excavations in 1830 for the foundation of a building at Abesse, a quantity of loose sand, which formed the slope *d e*, was removed; and a perpendicular cliff, about fifty feet in height, which had hitherto been protected from the agency of the elements, was exposed. At the bottom appeared the limestone *b*, containing tertiary shells and corals, immediately below it the clay (*c*), and above it the usual tertiary sand (*a*), of the department of the Landes. At the base of the precipice are seen large partially rounded masses of rock, evidently detached from the stratum *b*. The face of the limestone is hollowed out and weathered into such forms as are seen in the calcareous cliffs of the adjoining coast, especially at Biaritz, near Bayonne. It is evident that, when the country was at a somewhat lower level, the sea advanced along the surface of the

argillaceous stratum *c*, which, from its yielding nature, favoured the waste by allowing the more solid superincumbent stone *b* to be readily undermined. Afterwards, when the country had been elevated, part of the sand, *a*, fell down, or was drifted by the winds, so as to form the talus, *d e*, which masked the inland cliff until it was artificially laid open to view.

When we are considering the various causes which, in the course of ages, may efface the characters of an ancient sea-coast, earthquakes must not be forgotten. During violent shocks, steep and overhanging cliffs are often thrown down and become a heap of ruins. Sometimes unequal movements of upheaval or depression entirely destroy the horizontality of that base-line which constitutes the chief peculiarity of an ancient sea-cliff.

CHAPTER VII.

ALLUVIUM.

Alluvium described — Due to complicated causes — Of various ages, as shown in Auvergne — How distinguished from rocks *in situ* — River-terraces — Parallel roads of Glen Roy — Various theories respecting their origin.

Between the superficial covering of vegetable mould and the subjacent rock, there usually intervenes in every district a deposit of loose gravel, sand, and mud, to which the name of alluvium has been applied. The term is derived from *alluvio*, an inundation, or *alluo*, to wash, because the pebbles and sand commonly resemble those of a river's bed or the mud and gravel spread over low lands by a flood.

A partial covering of such alluvium is found alike in all climates, from the equatorial to the polar regions; but in the higher latitudes of Europe and North America it assumes a distinct character, being very frequently devoid of stratification, and containing huge fragments of rock, some angular and others rounded, which have been transported to great distances from their

parent mountains. When it presents itself in this form, it has been called "diluvium," "drift," or the "boulder formation;" and its probable connexion with the agency of floating ice and glaciers will be treated of more particularly in the tenth and eleventh chapters.

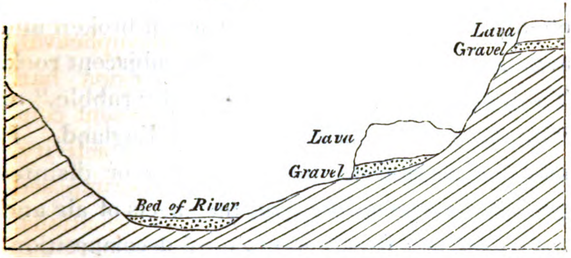
After what was said of denudation, the student will not be surprised to hear that loose gravel and sand are often met with at various points both on the summits and sides of mountains, and on the low grounds bordering rivers. For during the gradual emergence of land from the sea, or the changes which may take place in the physical geography of a district after it has been laid dry, any point may either have been a sunken reef, or the bottom of a bay or estuary, or a sea-shore, or the bed of a river. For this reason it would be unreasonable to hope that we should ever be able to account for all the alluvial phenomena of each particular country, seeing that the causes of their origin are so complicated. Moreover, the last operations of water have a tendency to disturb and confound together all pre-existing alluviums. Hence we are always in danger of regarding as the work of a single era, and the effect of one cause, what has in reality been the result of a variety of distinct agents, during a long succession of geological epochs. Much useful instruction may therefore be gained from the ex-

amination of a country like Auvergne, where the superficial gravel of very different eras happens to have been preserved by sheets of lava, which were poured out one after the other at periods when the denudation, and probably the upheaval, of rocks were in progress. That region had already acquired in some degree its present configuration before any volcanos were in activity, and before any igneous matter was superimposed upon the granitic and fossiliferous formations. The pebbles therefore in the older gravels are exclusively constituted of granite and other aboriginal rocks; and afterwards, when volcanic vents burst forth into eruption, those earlier alluviums were covered by streams of lava, which protected them from intermixture with gravel of subsequent date. In the course of ages, a new system of valleys was excavated, so that the rivers ran at lower levels than those at which the first alluviums and sheets of lava were formed. When therefore fresh eruptions gave rise to new lava, the melted matter was poured out over lower grounds; and the gravel of these plains differed from the first or upland alluvium, by containing in it rounded fragments of various volcanic rocks.

The annexed drawing will explain the different heights at which beds of lava and gravel, each distinct from the other in composition and age, are observed, some on the flat tops of hills, 700 or

800 feet high, others on the slope of the same hills, and the newest of all in the channel of the

Fig. 97.



Lavas of Auvergne resting on alluviums of different ages.

existing river where there is usually gravel alone, but in some cases a narrow thread of solid lava occupying together with the river the bottom of the valley. The streams in this country are still undermining their banks and grinding down into pebbles or sand columns of basalt and fragments of granite and gneiss; but the older alluviums, in which the bones of extinct quadrupeds have been detected, are prevented from being mingled with the gravel of recent date by the cappings of lava before mentioned. But for the accidental interference, therefore, of this peculiar cause, all the alluviums might have passed so insensibly the one into the other, that those formed at the remotest era might have appeared of the same date as the newest, and the whole formation might have been

regarded by some geologists as the result of one sudden and violent catastrophe.

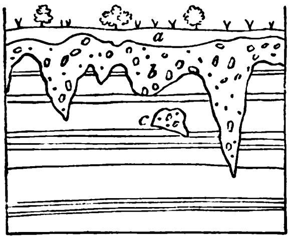
In almost every country, the alluvium consists in its upper part of transported materials, but it often passes downwards into a mass of broken and angular fragments derived from the subjacent rock. To this mass the provincial name of "rubble," or "brash," is given in many parts of England. It may be referred to the weathering or disintegration of stone on the spot, the effects of air and water, sun and frost, and chemical decomposition. Sometimes the vibrations and undulations of earthquakes may have had power, at some former era, to shatter a surface previously rent and weathered. Thus in Calabria, subterranean movements have been known to throw up into the air the slabs of a stone pavement *; and Mr. Darwin mentions, that in the Island of Quiriquina, in Chili, some narrow ridges of hard primary slate, which is there the fundamental rock, were as completely shivered by the vibrations of the great earthquake of February, 1835, as if they had been blasted by gunpowder. The effect was merely superficial, and had caused fresh fractures and displacement of the soil, the slate below remaining solid and uninjured.†

* See Princ. of Geol., Index, "Calabria."

† Darwin's Journal of Travels in S. America, &c. 1832 to 1836, in Voyage of H.M.S. Beagle, p. 370.

The inferior surface of alluvial deposits is often very irregular, conforming to all the inequalities of the fundamental rocks (Fig. 98.). Occasionally, a small mass, as at *c*, appears detached, and as if included in the subjacent formation. Such isolated portions are usually sections of winding subterranean hollows filled up with alluvium. They may have been the courses of springs or subterranean streamlets, which have flowed through and enlarged natural rents; or, when on a small scale and in soft strata, they may be spaces which the roots of large trees have once occupied, gravel and sand having been introduced after their decay.

Fig. 98.



a. vegetable soil. *b*. alluvium. *c*. mass of same, apparently detached.

It is not so easy as may at first appear to draw a clear line of distinction between the *fixed* rocks, or regular strata (rocks *in situ* or *in place*), and alluvium. If the bed of a torrent or river be dried up, we call the gravel, sand, and mud, left in their channels, or whatever, during floods, they may have scattered over the neighbouring plains, *alluvium*. The very same materials carried into a lake, where they become sorted by water and arranged in more distinct layers, are termed regular strata.

In the same manner we may often contrast the gravel, sand, and broken shells, strewed along the path of a rapid marine current, with a deposit formed contemporaneously by the discharge of similar materials, year after year, into a deeper and more tranquil part of the sea. In such cases, when we detect marine shells or other organic remains entombed in the strata, which enable us to determine their age and mode of origin, we regard them as part of the regular series of fossiliferous formations, whereas if there are no fossils, we have frequently no power of separating them from the general mass of superficial alluvium.

The usual rarity of organic remains in beds of loose gravel and sand is partly owing to the rapid and turbid water in which they were formed having been in a condition unfavourable to the habitation of aquatic beings, and partly to their porous nature, which, by allowing the free percolation of rain water, has promoted the decomposition and removal of organic matter.

It has long been a matter of common observation that rivers in general are now cutting their channels through alluvial deposits of greater depth and extent than could ever have been formed by the present streams. Now this may be explained, if we suppose a wide submarine area to have been raised by a gradual and uniform motion and made to emerge. In this case, friths,

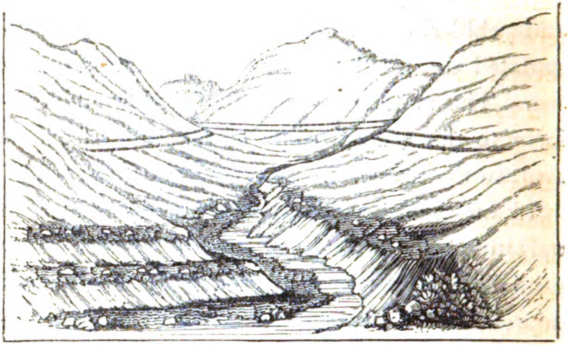
bays, estuaries, and the straits between islands, will dry up slowly, and during their conversion into valleys, every part may in its turn be a sea-shore, and may be strewed over with littoral sand and pebbles, or be the point where a delta accumulated during the retreat and exclusion of the sea. The materials so accumulated would conform to the general slope of the valley from its head to the sea-coast.

If, on the other hand, a country has not been upraised equally, but has been subject to many local convulsions accompanied by upheaval and depression, its drainage will be repeatedly deranged, and rivers will be made to forsake their ancient channels from time to time. During these wanderings, a large space may become covered with fluviatile detritus, through which we may find all the modern streams cutting their channels.

River terraces.—We often observe at a short distance from the present bed of a river a steep cliff a few feet or yards high, and on a level with the top of it a flat terrace corresponding in appearance to the alluvial plain which immediately borders the river. This terrace is again bounded by another cliff, above which a second terrace sometimes occurs; and in this manner two or three ranges of cliffs and terraces are occasionally seen on one or both sides of the stream, the number

varying, but those on the opposite sides often corresponding in height.

Fig. 99.



River Terraces and Parallel Roads.

These terraces are seldom continuous for great distances, and their surface is not horizontal, but slopes downwards, with an inclination similar to that of the river or valley. They are readily explained if we adopt the hypothesis before suggested, of a gradual rise of the land; for while this is going on new deposits, before submerged, are exposed to denudation, and in these the rivers shape out their beds. If the sea be deep where the valley terminates, every addition made to the height of the land by upheaval will rapidly augment the fall of the water, and at the same time its cutting power; and if, as is most probable, the upheaving move-

ment be intermittent, long pauses will occur, during which the stream will have time to encroach upon one of its banks, so as to clear away and flatten a large space. This operation being afterwards repeated at lower levels, there will be several successive cliffs and terraces.

Parallel roads.—The parallel roads, or shelves as they have been called, of Glen Roy and other valleys in Scotland, are distinct both in character and origin from the terraces above described; for they have no slope towards the sea like the channel of a river, nor are they the effect of denudation. Glen Roy is situated in the western Highlands, about ten miles north of Fort William, near the western end of the great glen of Scotland, or Caledonian Canal, and near the foot of the highest of the Grampians, Ben Nevis. Throughout its whole length, a distance of more than ten miles, two, and in its lower part three, parallel roads or shelves are traced along the steep sides of the mountains, as represented in Fig. 99., each maintaining a perfect horizontality, and continuing at exactly the same level on the opposite sides of the glen. Seen at a distance, they appear like ledges or roads, cut artificially out of the sides of the hills; but when we are upon them we can scarcely recognize their existence, so uneven is their surface, and so covered with boulders. They are from ten to sixty feet

broad, and merely differ from the side of the mountain by being somewhat less steep.

On closer inspection, we find that these terraces are stratified in the ordinary manner of alluvial or littoral deposits, as may be seen at those points where ravines have been excavated by torrents. The parallel shelves, therefore, have not been caused by denudation, but by the deposition of detritus, precisely similar to that which is dispersed in smaller quantities over the declivities of the hills above. These hills consist of clay-slate, mica-schist, and granite, which rocks have been worn away and laid bare at a few points only, in a line just above the parallel roads. The highest of these roads is about 1250 feet above the level of the sea, the next about 200 feet lower than the uppermost, and the third still lower by about 50 feet. It is only this last, or the lowest of the three, which is continued throughout Glen Spean, a large valley with which Glen Roy unites. As the shelves are always at the same height above the sea, they become continually more elevated above the river in proportion as we descend each valley; and they at length terminate very abruptly, without any obvious cause, either in the shape of the ground, or any change in the composition or hardness of the rocks. I should exceed the limits of this work,

were I to attempt to give a full description of all the geographical circumstances attending these remarkable terraces, or to discuss the ingenious theories which have been severally proposed to account for them by Dr. MacCulloch, Sir T. D. Lauder, Mr. Darwin, and Mr. Agassiz. There is one point, however, on which all are agreed, namely, that these shelves are ancient beaches, or littoral formations accumulated round the edges of one or more sheets of water which once stood at the level, first of the highest shelf, and successively at the height of the two others. It is well known, that wherever a lake or fiord exists surrounded by steep mountains subject to disintegration by frost or the action of torrents, some loose matter is washed down annually, especially during the melting of snow, and a check is given to the descent of this detritus at the point where it reaches the waters of the lake. The waves then spread out the materials along the shore, and throw some of them upon the beach; their dispersing power being aided by the ice, which often adheres to pebbles during the winter months, and gives buoyancy to them.

Among other proofs that the parallel roads have really been formed along the margin of a sheet of water, it may be mentioned, that wherever an isolated hill rises in the middle of the glen above the level of any particular shelf, a corresponding

shelf is seen at the same level passing round the hill, as would have happened if it had once formed an island in a lake or fiord.

Those writers who first advocated the doctrine that the roads were the ancient beaches of fresh-water lakes, were unable to offer any probable hypothesis respecting the formation and subsequent removal of barriers of sufficient height and solidity to dam up the water. To introduce any violent convulsion for their removal was inconsistent with the uninterrupted horizontality of the roads, and with the undisturbed aspect of those parts of the glens where the shelves come suddenly to an end. Mr. Agassiz has lately, however, thrown out a conjecture that these valleys were once blocked up by enormous glaciers descending from Ben Nevis, giving rise to what are called in Switzerland and in the Tyrol, glacier-lakes. After a time the icy barrier was broken down, or melted, first, to the level of the second, and afterwards to that of the third road or shelf.

In corroboration of this view, he contends that the alluvium of Glen Roy, as well as of other parts of Scotland, agrees in character with the moraines of glaciers seen in the Alpine valleys of Switzerland. Allusion will be made in the eleventh chapter to the former existence of glaciers in the Grampians: in the mean time it will readily be conceded that this hypothesis is preferable

to any previous lacustrine theory, by accounting more easily for the temporary existence and entire disappearance of lofty transverse barriers, although the height required for the imaginary dams of ice may be startling.

Before the idea last alluded to had been entertained, Mr. Darwin examined Glen Roy, and came to the opinion that the shelves were formed when the glens were still arms of the sea, and, consequently, that there never were any barriers. According to him, the land emerged during a slow and uniform upward movement, like that now experienced throughout a large part of Sweden and Finland; but there were certain pauses in the upheaving process, at which times the waters of the sea remained stationary for so many centuries as to allow of the accumulation of an extraordinary quantity of detrital matter, and the excavation, at points immediately above, of many deep notches and bare cliffs in the hard and solid rock.

The phenomena which are most difficult to reconcile with this theory are, first, the abrupt cessation of the roads at certain points in the different glens; secondly, their unequal number in different valleys connecting with each other, there being three, for example, in Glen Roy and only one in Glen Spean; thirdly, the precise horizontality of level maintained by the same shelf over a space many leagues in length requiring us to

assume, that during a rise of 1250 feet no one portion of the land was raised even a few yards above another.

On the other hand, it may be remarked, in reference to the rival hypothesis of glaciers, that it labours in some degree under precisely the same kind of difficulty, unless we could assume that the land had remained motionless since the era of the liquefaction of the ice. But there are many reasons for presuming that the glacial epoch (granting for the present that there were once glaciers in the Grampians) was antecedent to the deposition of those modern strata, of marine origin, which are found at various heights, from 40 to 400 feet above the sea, in the basins of the Clyde, Forth, Tay, Loch Ness, the Moray Firth, the Hebrides, and many other parts of Scotland. It seems improbable that Glen Roy should have escaped entirely the upward movement experienced in so many surrounding regions, a movement implied by the position of these elevated marine deposits, in which the shells are almost all of known recent species. But if the motion has really extended to Glen Roy and the contiguous glens, it must have uplifted them bodily, without in the slightest degree affecting their horizontality; and this being admitted, the principal objection to the theory of marine beaches, founded on the uniformity of up-

heaval, meets us equally when we embrace the glacier theory.

The student will perceive, from the above sketch of the controversy respecting the formation of these curious shelves, that this problem, like so many others in geology, is as yet only solved in part; and that a larger number of facts must be collected and reasoned upon before the question can be finally settled.

CHAPTER VIII.

ON THE CHRONOLOGY OF ROCKS IN GENERAL.

Aqueous, plutonic, volcanic, and metamorphic rocks, considered chronologically — Lehman's division into primitive and secondary — Werner's addition of a transition class — Neptunian theory — Hutton on igneous origin of granite — How the name of primary was still retained for granite — The term "transition," why faulty — The adherence to the old chronological nomenclature retarded the progress of geology — New hypothesis invented to reconcile the igneous origin of granite to the notion of its high antiquity — Explanation of the chronological nomenclature adopted in this work, so far as regards primary, secondary, and tertiary periods.

In the first chapter it was stated that the four great classes of rocks, the aqueous, the volcanic, the plutonic, and the metamorphic, would each be considered not only in reference to their mineral characters, and mode of origin, but also to their relative age. In regard to the aqueous rocks, we have already seen that they are stratified, that some are calcareous, others argillaceous, some made up of sand, others of pebbles; that some contain freshwater, others marine fossils, and so

forth; but the student has still to learn which rocks, exhibiting some or all of these characters, have originated at one period of the earth's history, and which at another.

To determine this point in reference to the fossiliferous formations is more easy than in any other class, and it is therefore the most convenient and natural method to begin by establishing a chronology for these fossiliferous strata, and then to endeavour to refer to the same divisions the several groups of plutonic, volcanic, and metamorphic rocks. This system of classification is not only recommended by its greater clearness and facility of application, but is also best fitted to strike the imagination by bringing into one view the past changes of the inorganic world, and the contemporaneous revolutions of the organic creation. For the sedimentary formations of successive periods are most readily distinguished by the different species of fossil animals and plants which they inclose, and of which one race after another has flourished and then disappeared from the earth.

But before entering specially on the subdivisions of the aqueous rocks arranged according to the order of time, it will be desirable to say a few words on the chronology of rocks in general, although in doing so we shall be led

to allude to some classes of phenomena which the beginner must not yet expect fully to comprehend.

It was for many years a received opinion, that the formation of entire families of rocks, such as the plutonic and metamorphic, began and ended before any members of the aqueous and volcanic orders were produced; and although this idea has long been modified, and is nearly exploded, it will be necessary to give some account of the ancient doctrine, in order that beginners may understand whence many prevailing opinions, and some part of the nomenclature of geology, still partially in use, was derived.

About the middle of the last century, Lehman, a German miner, proposed to divide rocks into three classes, the first and oldest to be called primitive, comprising the plutonic and metamorphic rocks; the next to be termed secondary, comprehending the aqueous or fossiliferous strata; and the remainder, or third class, the supposed effect of "local floods, and the deluge of Noah," corresponding to our alluvium, ancient and modern. In the primitive class, he said, such as granite and gneiss, there are no organic remains, nor any signs of materials derived from the ruins of pre-existing rocks. Their origin, therefore, may have been purely chemical, antecedent to the creation of living beings, and probably coeval

with the birth of the world itself. The secondary formations, on the contrary, which often contain sand, pebbles, and organic remains, must have been mechanical deposits, produced after the planet had become the habitation of animals and plants. This bold generalization, although anticipated in some measure by Steno, a century before, in Italy, formed at the time an important step in the progress of geology, and sketched out correctly some of the leading divisions into which rocks may be separated. About half a century later, Werner, so justly celebrated for his improved methods of discriminating the mineralogical characters of rocks, attempted to improve Lehman's classification, and with this view intercalated a class, called by him "the transition formations," between the primitive and secondary. Between these last he had discovered, in northern Germany, a series of strata, which in their mineral peculiarities were of an intermediate character, partaking in some degree of the crystalline nature of micaceous and clay-slate, and yet exhibiting here and there signs of a mechanical origin and organic remains. For this group, therefore, forming a passage between Lehman's primitive and secondary rocks, the name of transition was proposed. They consisted principally of clay-slate and an argillaceous sandstone, called greywacké,

and partly of calcareous beds. It happened in the district which Werner first investigated, that both the primitive and transition strata were highly inclined, while the beds of the newer and fossiliferous rocks were horizontal. To these latter, therefore, he gave the name of *flötz*, or flat; and every deposit more modern than the chalk, or uppermost of the flötz series, was designated "the overflowed land," an expression which may be regarded as equivalent to alluvium. As the followers of Werner soon discovered that the inclined position of the "transition beds," and the horizontality of the flötz, or newer fossiliferous strata, were mere local accidents, they soon abandoned the term flötz; and the four divisions of the Wernerian school were then named primitive, transition, secondary, and alluvium.

As to the trappean rocks, although their igneous origin had been already demonstrated by Arduino, Fortis, Faujas, and others, and especially by Desmarest, they were all regarded by Werner as aqueous, and as mere subordinate members of the secondary formations.*

This theory of Werner's was called the "Neptunian," and for many years enjoyed much popularity. It assumed that the globe had been at

* See Principles, vol. i. chap. iv.

first invested by an universal chaotic ocean, holding the materials of all rocks in solution. From the waters of this ocean, granite, gneiss, and other crystalline formations, were first precipitated; and afterwards, when the waters were purged of these ingredients, and more nearly resembled those of our actual seas, the transition strata were deposited. These were of a mixed character, not purely chemical, because the waves and currents had already begun to wear down solid land, and to give rise to pebbles, sand, and mud; nor entirely without fossils, because a few of the first marine animals had begun to exist. After this period, the secondary formations were accumulated in waters resembling those of the present ocean, except at certain intervals, when, from causes wholly unexplained, a partial recurrence of the "chaotic fluid" took place, during which various trap rocks, some highly crystalline, were formed. This arbitrary hypothesis rejected all intervention of igneous agency, volcanos being regarded as partial and superficial accidents, of trifling account among the great causes which have modified the external structure of the globe.

Meanwhile Hutton, a contemporary of Werner, began to teach, in Scotland, that granite as well as trap was of igneous origin, and had at various periods intruded itself in a fluid state into different parts of the earth's crust. He recognized

and faithfully described many of the phenomena of granitic veins, and the alterations produced by them on the invaded strata, which will be treated of in a future chapter. He, moreover, advanced the opinion, that the crystalline strata called primitive had not been precipitated from a primæval ocean, but were sedimentary strata altered by heat. In his writings, therefore, and in those of his illustrator, Playfair, we find the germ of that metamorphic theory which has been already hinted at in the first chapter, and which will be more fully expounded in the sequel.*

At length, after much controversy, the doctrine of the igneous origin of trap and granite made their way into general favour; but although it was, in consequence, admitted that both granite and trap had been produced at many successive periods, the term primitive or primary still continued to be applied to the crystalline formations in general, whether stratified, like gneiss, or unstratified, like granite. The pupil was told that granite was a primary rock, but that some granites were newer than certain secondary formations; and in conformity with the spirit of the ancient language, to which the teacher was still determined to adhere, a desire was naturally engendered of extenuating the importance of those

* See chapters on Metamorphic Rocks, Vol. II.

more modern granites which new observations were continually bringing to light.

A no less decided inclination was shown to persist in the use of the term "transition," after it had been proved to be almost as faulty in its original application as that of flötz. The name of transition, as already stated, was first given by Werner, to designate a mineral character, intermediate between the metamorphic state and that of an ordinary fossiliferous rock. But the term acquired also from the first a chronological import, because it had been appropriated to sedimentary formations, which, in the Hartz and other parts of Germany, were more ancient than the oldest of the secondary series, and were characterized by peculiar fossil zoophytes and shells. When, therefore, geologists found in other districts stratified rocks occupying the same position, and inclosing similar fossils, they gave to them also the name of *transition*, according to rules which will be explained in the next chapter; yet, in many cases, such rocks were found not to exhibit the same mineral texture which Werner had called transition. On the contrary, many of them were not more crystalline than different members of the secondary class; while, on the other hand, these last were sometimes found to assume a semi-crystalline and almost metamorphic aspect, and thus, on lithological grounds, to deserve equally the

name of transition. So remarkably was this the case in the Swiss Alps, that certain rocks, which had for years been regarded by some of the most skilful disciples of Werner to be transition, were at last acknowledged, when their relative position and fossils were better understood, to belong to the newest of the secondary groups! If under such circumstances the name of transition was retained, it is clear that it ought to have been applied without reference to the age of strata, and simply as expressive of a mineral peculiarity. The continued appropriation of the term to formations of a given date, induced geologists to go on believing that the ancient strata so designated bore a less resemblance to the secondary than is really the case, and to imagine that these last never pass, as they frequently do, into metamorphic rocks.

The poet Waller, when lamenting over the antiquated style of Chaucer, complains that —

> We write in sand, our language grows,
> And, like the tide, our work o'erflows;

But the reverse is true in geology; for here it is our work which continually outgrows the language. The tide of observation advances with such speed, that improvements in theory outrun the changes of nomenclature; and the attempt to inculcate new truths by words invented to express a different or opposite opinion, tends constantly, by the

force of association, to perpetuate error; so that dogmas renounced by the reason still retain a strong hold upon the imagination.

In order to reconcile the old chronological views with the new doctrine of the igneous origin of granite, the following hypothesis was substituted for that of the Neptunists. Instead of beginning with an aqueous menstruum or chaotic fluid, the materials of the present crust of the earth were supposed to have been at first in a state of igneous fusion, until part of the heat having been diffused into surrounding space, the surface of the fluid consolidated, and formed a crust of granite. This covering of crystalline stone, which afterwards grew thicker and thicker as it cooled, was so hot, at first, that no water could exist upon it; but as the refrigeration proceeded, the aqueous vapour in the atmosphere was condensed, and, falling in rain, gave rise to the first *thermal ocean*. So high was the temperature of this boiling sea, that no aquatic beings could inhabit its waters, and its deposits were not only devoid of fossils, but, like those of some hot springs, were highly crystalline. Hence the origin of the primary or crystalline strata.

Afterwards, when the granitic crust had been partially broken up, land and mountains began to rise above the waters, and rains and torrents ground down rock, so that sediment was spread

over the bottom of the seas. Yet the heat still remaining in the solid supporting substances was sufficient to increase the chemical action exerted by the water, although not so intense as to prevent the introduction and increase of some living beings. During this state of things some of the residuary mineral ingredients of the primæval ocean were precipitated, and formed deposits (the transition strata of Werner), half chemical and half mechanical, and containing a few fossils.

By this new theory, which was in part a revival of the doctrine of Leibnitz, published in 1680, on the igneous origin of the planet, the old ideas respecting the priority of all crystalline rocks to the creation of organic beings, were still preserved; and the notion that all the semi-crystalline and partially fossiliferous rocks belonged to one period, while all the earthy and uncrystalline formations originated at a subsequent epoch, was also perpetuated.

It may or may not be true, as the great Leibnitz imagined, that the whole planet was once in a state of liquefaction by heat; but there are certainly no geological proofs that the granite which constitutes the foundation of so much of the earth's crust was ever at once in a state of universal fusion. On the contrary, all our evidence tends to show that the formation of granite, like the deposition of the stratified rocks, has been successive, and that

different portions of granite have been in a melted state at distinct and often distant periods. One mass was solid, and had been fractured, before another body of granitic matter was injected into it, or through it, in the form of veins. In short, the universal fluidity of the crystalline foundations of the earth's crust, can only be understood in the same sense as the universality of the ancient ocean. All the land has been under water, but not all at one time; so all the subterranean unstratified rocks to which man can obtain access have been melted, but not simultaneously.

In the present work the four great classes of rocks, the aqueous, plutonic, volcanic, and metamorphic, will form four parallel, or nearly parallel, columns in one chronological table. They will be considered as four sets of monuments relating to four contemporaneous, or nearly contemporaneous, series of events. I have endeavoured, in the Frontispiece and in a subsequent chapter on the plutonic rocks, to express the manner in which members of each of the four classes may have originated simultaneously at every geological period. According to this view, the earth's crust may have been continually remodelled, above and below, by aqueous and igneous causes, from times indefinitely remote. In the same manner as aqueous and fossiliferous strata are now formed in certain seas or lakes, while in other places volcanic rocks break out at

the surface, and are connected with reservoirs of melted matter at vast depths in the bowels of the earth,—so, at every era of the past, fossiliferous deposits and superficial igneous rocks were in progress contemporaneously with others of subterranean and plutonic origin, and some sedimentary strata were exposed to heat and made to assume a crystalline or metamorphic structure.

It can by no means be taken for granted, that during all these changes the solid crust of the earth has been increasing in thickness. It has been shown, that so far as aqueous action is concerned, the gain by fresh deposits, and the loss by denudation, must at each period have been equal; and in like manner, in the inferior portion of the earth's crust, the acquisition of new crystalline rocks, at each successive era, may merely have counterbalanced the loss sustained by the melting of materials previously consolidated. As to the relative antiquity of the crystalline foundations of the earth's crust, when compared to the fossiliferous and volcanic rocks which they support, I have already stated, in the first chapter, that to pronounce an opinion on this matter is as difficult as at once to decide which of the two, whether the foundations or superstructure of an ancient city built on wooden piles may be the oldest. We have seen that to answer this question, we must first be prepared to say whether the work of decay and re-

storation had gone on most rapidly above or below, whether the average duration of the piles has exceeded that of the stone buildings, or the contrary. So also in regard to the relative age of the superior and inferior portions of the earth's crust; we cannot hazard even a conjecture on this point, until we know whether, upon an average, the power of water above, or that of fire below, is most efficacious in giving new forms to solid matter.

After the observations which have now been made, the reader will perceive that the term primary must either be entirely renounced, or, if retained, must be differently defined, and not made to designate a set of crystalline rocks, some of which may be newer than the secondary formations. In this work I shall follow most nearly the method proposed by Mr. Boué, who has called all fossiliferous rocks older than the secondary by the name of primary, which thus becomes a substitute for the term transition, so far as regards the aqueous strata. To prevent confusion, however, I shall always speak of these as the *primary fossiliferous* formations, because the word primary has hitherto been almost inseparably connected with the idea of a non-fossiliferous rock.

If we can prove any plutonic, volcanic, or metamorphic rocks to be older than the secondary formations, such rocks will also be primary, according to this system. Mr. Boué having with

great propriety excluded the metamorphie rocks, *as a class*, from the primary formations, proposed to call them all "crystalline schists," restricting the name of primary to the older fossiliferous or transition strata.

As there are secondary fossiliferous strata, so we shall find that there are plutonic, volcanic, and metamorphic rocks of contemporaneous origin, which I shall also term secondary.

In the next chapter it will be shown that the strata above the chalk have been called tertiary. If, therefore, we discover any volcanic, plutonic, or metamorphic rocks, which have originated since the deposition of the chalk, these also will rank as tertiary formations.

It may perhaps be suggested that some metamorphic strata, and some granites, may be anterior in date to the oldest of the primary fossiliferous rocks. The opinion is certainly not improbable, and will be discussed in future chapters; but I may here observe, that when we arrange the four classes of rocks in four parallel columns in one table of chronology, it is by no means assumed that these columns are all of equal length; one may begin at an earlier period than the rest, and another may come down to a later point of time. In the small part of the globe hitherto examined, it is hardly to be expected that we should have discovered either the oldest or the newest of all

the four classes of rocks. Thus, if there be primary, secondary, and tertiary rocks of the fossiliferous class, and in like manner primary, secondary, and tertiary plutonic formations, we may not be yet acquainted with the most ancient of the primary fossiliferous beds, or with the newest of the plutonic, and so of the rest.

CHAPTER IX.

ON THE DIFFERENT AGES OF THE AQUEOUS ROCKS.

On the three principal tests of relative age — superposition, mineral character, and fossils — Change of mineral character and fossils in the same continuous formation — Proofs that distinct species of animals and plants have lived at successive periods — Distinct provinces of indigenous species — Great extent of single provinces — Similar laws prevailed at successive geological periods — Relative importance of mineral and palæontological characters — Test of age by included fragments — Frequent absence of strata of intervening periods — Principal groups of strata in western Europe — Post-Pliocene formations defined — Fossil shells — Recent and Post-Pliocene strata of Naples, Sweden, Norway, S. America, the West Indies, and Great Britain.

In the last chapter I spoke generally of the chronological relations of the four great classes of rocks, and I shall now treat of the aqueous rocks in particular, or of the successive periods at which the different fossiliferous formations have been deposited.

Now there are three principal tests by which we determine the age of a given set of strata; first, superposition; secondly, mineral character; and, thirdly, organic remains. Some aid can occasionally be derived from a fourth kind of proof,

namely, the fact of one deposit including in it fragments of a pre-existing rock, by which the relative ages of the two may, even in the absence of all other evidence, be determined.

Superposition.—The first and principal test of the age of one aqueous deposit, as compared to another, is relative position. It has been already stated, that where the strata are horizontal, the bed which lies uppermost is the newest of the whole, and that which lies at the bottom the most ancient. So, of a series of sedimentary formations, they are like volumes of history, in which each writer has recorded the annals of his own times, and then laid down the book, with the last written page uppermost, upon the volume in which the events of the era immediately preceding were commemorated. In this manner a lofty pile of chronicles is at length accumulated; and they are so arranged as to indicate, by their position alone, the order in which the events recorded in them have occurred.

In regard to the crust of the earth, however, there are some regions where, as the student has already been informed, the beds have been disturbed, and sometimes reversed. (See pp. 124, 125.) But the experienced geologist will not be deceived by these exceptional cases. When he finds that the strata are fractured, curved, inclined, or vertical, he knows that the original

order of superposition must be doubtful, and he will endeavour to find sections in some neigbouring district where the strata are horizontal, or only slightly inclined. Here, it is impossible that they can have been extensively thrown over and turned upside down, for such a derangement cannot have taken place throughout a wide area without leaving manifest signs of displacement and dislocation.

Mineral character.—The same rocks may often be observed to retain for miles, or even hundreds of miles, the same mineral peculiarities, if we follow the planes of stratification, or trace the beds, if they be undisturbed, in a horizontal direction. But if we pursue them vertically, or in any direction transverse to the planes of stratification, this uniformity ceases almost immediately. In that case we can scarcely ever penetrate a stratified mass for a few hundred yards without beholding a succession of extremely dissimilar, calcareous, argillaceous, and siliceous rocks. These phenomena lead to the conclusion, that rivers and currents have dispersed the same sediment over wide areas at one period, but at successive periods have been charged, in the same region, with very different kinds of matter. The first observers were so astonished at the vast spaces over which they were able to follow the same homogeneous rocks in a horizontal direction, that they came hastily

to the opinion, that the whole globe had been environed by a succession of distinct aqueous formations, disposed round the nucleus of the planet, like the concentric coats of an onion. But although, in fact, some formations may be continuous over districts as large as half of Europe, or even more, yet most of them either terminate wholly within narrower limits, or soon change their lithological character. Sometimes they thin out gradually, as if the supply of sediment had failed in that direction, or they come abruptly to an end, as if we had arrived at the borders of the ancient sea or lake which served as their receptacle. It no less frequently happens that they vary in mineral aspect and composition, as we pursue them horizontally. For example, we trace a limestone for a hundred miles, until it becomes more arenaceous, and finally passes into sand, or sandstone. We may then follow this sandstone, already proved by its continuity to be of the same age, throughout another district a hundred miles or more in length.

Organic remains. — This character must be used as a criterion of the age of a formation, or of the contemporaneous origin of two deposits in distant places, under very much the same restrictions as the test of mineral composition.

First, the same fossils may be traced over wide regions, if we examine strata in the direction of

their planes, although by no means for indefinite distances.

Secondly, while the same fossils prevail in a particular set of strata for hundreds of miles in a horizontal direction, we seldom meet with the same remains for many fathoms, and very rarely for several hundred yards, in a vertical line, or a line transverse to the strata. This fact has now been verified in almost all parts of the globe, and has led to a conviction, that at successive periods of the past, the same area of land and water has been inhabited by species of animals and plants as distinct as those which now people the antipodes, or which now co-exist in the arctic, temperate, and tropical zones. It appears, that from the remotest periods there has been ever a coming in of new organic forms, and an extinction of those which pre-existed on the earth; some species having endured for a longer, others for a shorter time; while none have ever re-appeared after once dying out. The law which has governed the creation and extinction of species seems to be expressed in the verse of the poet, —

> Natura il fece, e poi ruppe la stampa. ARIOSTO.
>
> Nature made it, and then broke the die.

And this circumstance it is, which confers on fossils their highest value as chronological tests, giving to each of them, in the eyes of the geo-

logist, that authority which belongs to contemporary medals in history.

The same cannot be said of each peculiar variety of rock; for some of these, as red marl and red sandstone, for example, may occur at once at the top, bottom, and middle of the entire sedimentary series; exhibiting in each position so perfect an identity of mineral aspect as to be undistinguishable. Such exact repetitions, however, of the same mixtures of sediment have not often occurred, at distant periods, in precisely the same parts of the globe; and even where this has happened, we may usually avoid confounding together the monuments of remote eras, by the aid of fossils and relative position.

It was remarked that the same species of fossils cannot be traced horizontally, or in the direction of the planes of stratification for indefinite distances. This might have been expected from analogy; for when we inquire into the present distribution of organic beings, we find that the habitable surface of the sea and land may be divided into a considerable number of distinct provinces, each peopled by a peculiar assemblage of animals and plants. In the Principles of Geology, I endeavoured to point out the probable origin of these separate divisions; and it was shown that climate is only one of many causes on which they depend, and that difference of lon-

gitude as well as latitude is generally accompanied by a dissimilarity of indigenous species.

As different seas, therefore, and lakes are inhabited at the same period, by different aquatic animals and plants, and as the lands adjoining these may be peopled by distinct terrestrial species, it follows that distinct fossils will be imbedded in contemporaneous deposits. If it were otherwise—if the same species abounded in every climate, or in every part of the globe where, so far as we can discover, a corresponding temperature and other conditions favourable to their existence are found—the identification of mineral masses of the same age, by means of their included organic contents, would be a matter of much greater facility.

But the extent of the same zoological provinces, especially those of marine animals, is very great; and our geological researches have proved that the same laws prevailed at remote periods; for the fossils are often identical throughout wide spaces, and in a great number of detached deposits, in which the mineral nature of the rocks is variable.

The doctrine here laid down will be more readily understood, if we reflect on what is now going on in the Mediterranean. That entire sea may be considered as one zoological province; for, although certain species of testacea and zoo-

phytes may be very local, and each region has probably some species peculiar to it, still a considerable number are common to the whole Mediterranean. If, therefore, at some future period, the bed of this inland sea should be converted into land, the geologist might be enabled, by reference to organic remains, to prove the contemporaneous origin of various mineral masses scattered over a space equal in area to the half of Europe.

The deposits alluded to are those which are well known to be now in progress in the deltas of the Po, Rhone, Nile, and other rivers, the sediment of which differs as greatly as does the composition of the mountains which they drain. There are also other quarters of the Mediterranean, as off the coast of Campania, or near the base of Etna, in Sicily, or in the Grecian Archipelago, where other kinds of rocks are now forming. Occasional showers of volcanic ashes fall into the sea, and streams of lava overflow its bottom; and in the intervals between volcanic eruptions, beds of sand and clay are frequently derived from the waste of cliffs, or the turbid waters of rivers. Limestones, moreover, such as the Italian travertins, are here and there precipitated from the waters of mineral springs, some of which rise up from the bottom of the sea. In all these detached formations, so diversified in their lithological cha-

racters, the remains of the same shells, corals, crustacea, and fish are becoming inclosed; or, at least, a sufficient number must be common to the different localities to enable the zoologist to refer them all to one contemporaneous assemblage of species.

There are, however, certain combinations of geographical circumstances which cause distinct provinces of animals and plants to be separated from each other by very narrow limits; and hence it must happen, that strata will be sometimes formed in contiguous regions, differing widely both in mineral contents and organic remains. Thus, for example, the testacea, zoophytes, and fish of the Red Sea are, as a group, extremely distinct from those inhabiting the adjoining parts of the Mediterranean, although the two seas are separated only by the narrow isthmus of Suez. Calcareous formations have accumulated on a great scale in the Red Sea in modern times, and fossil shells of existing species are well preserved therein; and we know that at the mouth of the Nile large deposits of mud are amassed, including the remains of Mediterranean species. It follows, therefore, that if at some future period the bed of the Red Sea should be laid dry, the geologist might experience great difficulties in endeavouring to ascertain the relative age of these formations, which, although dissimilar both in

organic and mineral characters, were of synchronous origin.

But we must not forget that the north-western shores of the Arabian Gulf, the plains of Egypt, and the isthmus of Suez, are all parts of one province of *terrestrial* species. Small streams, therefore, occasional land-floods, and those winds which drift clouds of sand along the deserts, might carry down into the Red Sea the same shells of fluviatile and land testacea which the Nile is sweeping into its delta, together with some remains of terrestrial plants, whereby the groups of strata, before alluded to, might notwithstanding the discrepancy of their mineral composition, and *marine* organic fossils, be shown to have belonged to the same epoch.

But while rivers may thus carry down the same fluviatile and terrestrial spoils into two or more seas inhabited by different marine species, it will much more frequently happen, that the co-existence of terrestrial species of distinct zoological and botanical provinces will be proved by the identity of the marine beings which inhabited the intervening space. Thus, for example, the land quadrupeds and shells of the south of Europe, north of Africa, and north-west of Asia, are different, yet their remains are all washed down by rivers flowing from these three countries into the Mediterranean.

In some parts of the globe, at the present period, the line of demarcation between distinct provinces of animals and plants is not very strongly marked, especially where the change is determined by temperature, as in seas extending from the temperate to the tropical zone, or from the temperate to the arctic regions. Here a gradual passage takes place from one set of species to another. In like manner the geologist, in studying particular formations of remote periods, has sometimes been able to trace the gradation from one ancient province to another, by observing carefully the fossils of all the intermediate places. His success in thus acquiring a knowledge of the zoological or botanical geography of very distant eras has been mainly owing to this circumstance, that the mineral character has no tendency to be affected by climate. A large river may convey yellow or red mud into some part of the ocean, where it may be dispersed by a current over an area several hundred leagues in length, so as to pass from the tropics into the temperate zone. If the bottom of the sea be afterwards upraised, the organic remains imbedded in such yellow or red strata may indicate the different animals or plants which once inhabited at the same time the temperate and equatorial regions.

It may be true, as a general rule, that groups of the same species of animals and plants may ex-

tend over wider areas than deposits of homogeneous composition; and if so, palæontological characters will be of more importance in geological classification than mineral composition; but it is idle to discuss the relative value of these tests, and it fortunately happens, that where the one criterion fails, we can often avail ourselves of the other.

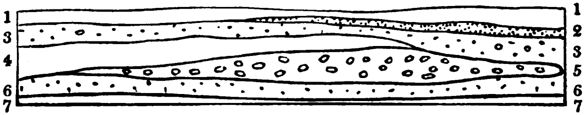
Test by included fragments of older rocks. — It was stated, that independent proof may sometimes be obtained of the relative date of two formations, by fragments of an older rock being included in a newer one. This evidence may sometimes be of great use, where a geologist is at a loss to determine the relative age of two formations, from want of clear sections exhibiting their true order of position, or because the strata of each group are vertical. In such cases we sometimes discover that the more modern rock has been in part derived from the degradation of the older. Thus, for example, we may find in one part of a country chalk with flints; and, in another, a distinct formation, consisting of alternations of clay, sand, and pebbles. If some of these pebbles consist of flints, with fossil shells of the same species as those in the chalk, we may confidently infer that the chalk is the oldest of the two formations.

Chronological groups. — The number of groups into which the fossiliferous strata may be separated are more or less numerous, according to the views

of classification which different geologists entertain; but when we have adopted a certain system of arrangement, we immediately find that a few only of the entire series of groups occur one upon the other in any single section or district.

The thinning out of individual strata was before described (p. 34.). But let the annexed diagram

Fig. 100.



represent seven fossiliferous groups, instead of as many strata. It will then be seen that in the middle all the superimposed formations are present; but in consequence of some of them thinning out, No. 2. and No. 5. are absent at one extremity of the section, and No. 4. at the other.

If the reader consults the Frontispiece, he will see, that as the yellow-coloured strata A rest unconformably upon the older groups, *c*, *e*, *f*, *g*, we should meet with a very different succession in a vertical section exposed at different places; in one spot the beds A, lying immediately on *c*, in another on *g*, and so forth. Now here the difference has been partly occasioned by denudation; the formations *a*, *b*, for instance, once extended much farther to the left, and but for denudation would have been every where interposed between

A and the rocks *e*, *f*, *g*. In many instances the entire absence of one or more formations of intervening periods between two groups, such as A and *c* (see Frontispiece), arises, not from the destruction of what once existed, by denudation, but because no strata of an intermediate age were ever deposited on *c*. They were not formed at that place, either because the region was dry land during the interval, or because it was part of a sea or lake to which no sediment was carried.

In order, therefore, to establish a chronological succession of fossiliferous groups, a geologist must begin with a single section, in which several sets of strata lie one upon the other. He must then trace these formations, by attention to their mineral character and fossils, continuously, as far as possible, from the starting point. As often as he meets with new groups, he must ascertain by superposition their age relatively to those first examined, and thus learn how to intercalate them in a tabular arrangement of the whole.

By this means the German, French, and English geologists have determined the succession of strata throughout a great part of Europe, and have adopted pretty generally the following groups, almost all of which have their representatives in the British Islands.

Groups of Fossiliferous Strata observed in Western Europe, arranged in what is termed a descending Series, or beginning with the newest.

1. Post-Pliocene, including those of the Recent, or human period.	
2. Newer Pliocene. 3. Older Pliocene. 4. Miocene. 5. Eocene.	Tertiary or Supracretaceous.*
6. Chalk. 7. Greensand. 8. Wealden. 9. Upper Oolite. 10. Middle Oolite. 11. Lower Oolite. 12. Lias. 13. Upper New Red sandstone and Muschelkalk. 14. Lower New Red and Magnesian limestone. 15. Coal. 16. Old Red sandstone and Devonian	Secondary.
17. Upper Silurian. 18. Lower Silurian. 19. Cambrian and older fossiliferous strata.	Primary fossiliferous (or transition of some authors.)

A glance at the above table will show that the three principal sections, called primary fossiliferous, secondary, and tertiary, are by no means of equivalent importance, if the eighteen subordinate groups comprise monuments relating to equal

* For tertiary, Mr. De la Beche has used the term "supracretaceous," a name implying that the strata so called are superior in position to the chalk.

portions of past time, or of the earth's history. But this we cannot assert; but merely know that they each relate to successive periods, during which certain animals and plants, for the most part peculiar to that era, flourished, and during which different kinds of sediment were deposited in the space now occupied by Europe.

If we were disposed, on palæontological grounds, to divide the entire fossiliferous series into a few groups, less numerous than those in the above table, and more nearly co-ordinate in value than the sections called primary, secondary, and tertiary, we might, perhaps, adopt the six following groups or periods.*

Fossiliferous Strata of Western Europe divided into Six Groups.

1. Post-Pliocene and Tertiary	from the Post-Pliocene to the Eocene inclusive.
2. Cretaceous	from the Chalk to the Wealden inclusive.
3. Oolitic	from the Portland Oolite to the Lias inclusive.
4. Upper New Red	including the Keuper, Muschelkalk, and Bunter Sandstein of the Germans.
5. Lower New Red and Carboniferous	including Magnesian Limestone (Zechstein), Coal, and Old Red sandstone.
6. Primary fossiliferous	from the Upper Silurian to the oldest fossiliferous rocks inclusive.

* Palæontology is the science which treats of fossil re-

At the same time I may observe, that in the present state of the science, when we have not yet compared the evidence derivable from all classes of fossils, not even those most generally distributed, such as shells, corals, and fish, such generalizations are premature, and can only be regarded as conjectural schemes for the founding of large natural groups.

In the first of the foregoing tables (p. 210.) I have adopted the term Post-Pliocene for those strata which are sometimes called modern, and which are characterized by having all the imbedded fossil shells identical with species now living, whereas even the Newer Pliocene or newest of the tertiary deposits contain always some small proportion of shells of extinct species.*

These modern formations, thus defined, comprehend not only those strata which can be shown to have originated since the earth was inhabited by man, but also deposits of far greater extent and thickness, in which no signs of man or his works can be detected. In some of these, of a date long anterior to the times of history and tradition, the bones of extinct quadrupeds have been met with of species which probably never

mains, both animal and vegetable. *Etym.* παλαιος, *palaios*, ancient, οντα, *onta*, beings, and λογος, *logos*, a discourse.

* See explanation of the term Pliocene, chap. xii.

co-existed with the human race, as, for example, the mammoth, and yet the shells are the same as those now living.

Before enlarging farther on these topics, it may be well to explain why the testacea are selected as the most useful and convenient class of fossil remains for the purposes of general classification. In the first place, they are more universally distributed through strata of every age than any other organic bodies. Those families of fossils which are of rare and casual occurrence are absolutely of no avail in establishing a chronological arrangement. If we have plants alone in one group of strata and the bones of mammalia in another, we can draw no conclusion respecting the affinity or discordance of the organic beings of the two epochs compared; and the same may be said if we have plants and vertebrated animals in one series and only shells in another. Although corals are more abundant, in a fossil state, than plants, reptiles, or fish, they are still rare when contrasted with shells, especially in the European tertiary formations. The utility of the testacea is, moreover, enhanced by the circumstance that some forms are proper to the sea, others to the land, and others to freshwater. Rivers scarcely ever fail to carry down into their deltas some land shells, together with species which are at once fluviatile and lacustrine. By this means we learn

what terrestrial, freshwater, and marine species co-existed at particular eras of the past; and having thus identified strata formed in seas, with others which originated contemporaneously in inland lakes, we are then enabled to advance a step farther, and show that certain quadrupeds or aquatic plants, found fossil in lacustrine formations, inhabited the globe at the same period when certain fish, reptiles, and zoophytes lived in the ocean.

Among other characters of the molluscous animals, which render them extremely valuable in settling chronological questions in geology, may be mentioned, first, the wide geographical range of many species; and, secondly, what is probably a consequence of the former, the great duration of species in this class, for they appear to have surpassed in longevity the greater number of the mammalia and fish. Had each species inhabited a very limited space, it could never, when imbedded in strata, have enabled the geologist to identify deposits at distant points; or had they each lasted but for a brief period, they could have thrown no light on the connection of rocks placed far from each other in the chronological, or, as it is often termed, vertical series.

That portion of the post-pliocene group which belongs to the human epoch, and which is sometimes called *Recent*, forms a very insignificant

feature in the geological structure of the earth's crust. I have shown, however, in another work, where the recent changes of the earth illustrative of geology are described at length, that the deposits accumulated at the bottom of lakes and seas within the last 4000 or 5000 years can neither be insignificant in volume or extent. They lie hidden, for the most part, from our sight; but we have opportunities of examining them at certain points where newly-gained land in the deltas of rivers has been cut through during floods, or where coral reefs are growing rapidly, or where the bed of a sea or lake has been heaved up by subterranean movements and laid dry. Their age may be recognized either by our finding in them the bones of man in a fossil state, that is to say, imbedded in them by natural causes, or by their containing articles fabricated by the hands of man.

Thus at Puzzuoli, near Naples, marine strata are seen containing fragments of sculpture, pottery, and the remains of buildings, together with innumerable shells retaining in part their colour, and of the same species as those now inhabiting the Bay of Baiæ. The uppermost of these beds is about twenty feet above the level of the sea. Their emergence can be proved to have taken place since the beginning of the sixteenth cen-

tury.* Now here, as in almost every instance where any alterations of level have been going on in historical periods, it is found that rocks containing shells, all, or nearly all of which still inhabit the neighbouring sea, may be traced for some distance into the interior, and often to a considerable elevation above the level of the sea. Thus, in the country round Naples, the post-pliocene strata, consisting of clay and horizontal beds of volcanic tuff, rise at certain points to the height of 1500 feet. Although the marine shells are exclusively of living species, they are not accompanied like those on the coast at Puzzuoli by any traces of man or his works. Had any such been discovered, it would have afforded to the antiquary and geologist matter of great surprise, since it would have shown that man was an inhabitant of that part of the globe, while the materials composing the present hills and plains of Campania were still in the progress of deposition at the bottom of the sea; whereas we know that for nearly 3000 years, or from the times of the earliest Greek colonists, no material revolution in the physical geography of that part of Italy has occurred.

In Ischia, a small island near Naples, composed in like manner of marine and volcanic formations,

* See Principles, Index, "Serapis."

Dr. Philippi collected in the stratified tuff and clay ninety-two species of shells, all of which, except three, are already known to exist in the Mediterranean, and the others may yet perhaps be discovered. In the centre of Ischia, the lofty hill called Epomeo, or San Nicola, is composed of greenish indurated tuff, of a prodigious thickness, interstratified in some parts with marl, and here and there with great beds of solid lava. Visconti ascertained by trigonometrical measurement, that this mountain was 2605 feet above the level of the sea. Not far from its summit, at the height of about 2000 feet, as also near Moropano, a village only 100 feet lower, on the southern declivity of the mountain, I collected, in 1828, many shells of species now inhabiting the neighbouring gulf. It is clear, therefore, that the great mass of Epomeo was not only raised to its present height, but was also *formed* beneath the waters, within the Post-Pliocene period.

In Sweden, analogous phenomena have been observed. Near Stockholm, for example, when the canal of Södertelje was dug, horizontal beds of sand, loam, and marl were passed through, in some of which the same peculiar assemblage of testacea which now live in the brackish waters of the Baltic were found. Mingled with these, at different depths, were detected various works of art implying a rude state of civilization, and some

vessels built before the introduction of iron. These vessels and implements must have sunk to the bottom of an arm of the sea, afterwards filled up with sand and loam inclosing marine shells, and the whole must then have been upraised; so that the upper beds became sixty feet higher than the surface of the Baltic. In the neighbourhood of these recent strata, both to the north-west and south of Stockholm, other deposits similar in mineral composition occur, which ascend to greater heights, in which precisely the same assemblage of fossil shells is met with, but without any intermixture of human bones or fabricated articles.

On the opposite or western coast of Sweden, at Uddevalla, Post-Pliocene strata, containing recent shells, such as now live in the northern ocean, ascend to the height of 200 feet; and beds of clay and sand of the same age attain elevations of 300 and even 600 feet in Norway, where they have been usually described as raised beaches. They are, however, thick deposits of submarine origin, spreading far and wide, and filling valleys in the granite and gneiss, just as the tertiary formations, in different parts of Europe, cover or fill depressions in the older rocks. It has been ascertained that, in various parts of Finland and Sweden, land has been rising gradually at the rate of a few feet, and sometimes only a few inches, in a century, above its former level; and similar move-

ments must evidently have been experienced in Norway, since the ocean was peopled with the species of testacea now inhabiting its waters.

Examples might be cited in all parts of the world of the same phenomena. Thus, Recent strata have been traced along the coasts of Peru and Chili, inclosing shells in abundance, all agreeing specifically with those now swarming in the Pacific. In one bed of this kind, in the island of San Lorenzo, near Lima, Mr. Darwin found, at the altitude of eighty-five feet above the sea, pieces of cotton-thread, plaited rush, and the head of a stalk of Indian corn, the whole of which had evidently been imbedded with the shells. At the same height on the neighbouring mainland, he found other signs corroborating the opinion that the ancient bed of the sea had there also been uplifted eighty-five feet, since the region was first peopled by the Peruvian race.* But similar shelly masses are also met with at much higher elevations, at innumerable points between the Chilian and Peruvian Andes, and the sea-coast, in which no human remains were ever, or in all probability ever will be, discovered.

In the West Indies, also, in the island of Guadaloupe, a solid limestone occurs, at the level of the sea-beach, enveloping human skeletons. The

* Journal, p. 451.

stone is extremely hard, and chiefly composed of comminuted shell and coral, with here and there some entire corals and shells, of species now living in the adjacent ocean. With them are included arrow-heads, fragments of pottery, and other articles of human workmanship. A limestone with similar contents has been formed, and is still forming, in St. Domingo. But there are also more ancient rocks in the West Indian Archipelago, as in Cuba, near the Havanna, and in other islands, in which are shells identical with those now living in corresponding latitudes; some well preserved, others in the state of casts, all referable to the Post-Pliocene period.

In England, buried ships have been found in the former and now deserted channels of the Rother in Sussex, of the Mersey in Kent, and the Thames near London. Canoes and stone-hatchets have been dug up, in almost all parts of the kingdom, from peat and shell-marl; but there is no evidence, as in Sweden, Italy, Peru, Chili, and other parts of the world, of the bed of the sea, and the adjoining coast, having been uplifted bodily in recent times. In Ireland, however, the greater part of a human skeleton has been lately found at Waterford Haven, in an undisturbed marine stratum, containing the common mussel, cockle, and other shells of recent species, some of which were found in the cavity of the skull. The

bed consisted of sand and clay, and was five feet below the surface of the soil, and five feet above the level of high-tide. Other parts of the same formation extend eight miles inland, and reach a height of forty feet above the sea.*

* T. Austin, Proceedings Geol. Soc. No. 74.

CHAPTER X.

BOULDER FORMATION, ITS AGE, AND ORIGIN.

Boulder formation of Scandinavia, Russia, and northern Germany described — Till — Erratics diminishing in size when traced southwards — They rest on Post-Pliocene strata in Russia and Sweden — Drift of eastern Norfolk — Associated freshwater deposit — Bent and folded strata lying on horizontal and undisturbed beds — Lateral pressure of stranded icebergs — Drifting of stones by ice in northern and southern hemispheres — Cause of non-stratification of Till — Buried forest in Norfolk — Boulder formation of Canada, and arctic character of accompanying shells.

Mention was made in the seventh chapter of an ancient alluvium in the north of Europe, called the "boulder formation," the peculiar characters and probable age of which must now be considered. I shall first describe briefly that portion of it which extends from Finland and the Scandinavian mountains to the north of Russia, and the low countries bordering the Baltic, and which has been traced southwards as far as the eastern coast of England. This formation consists of mud, sand, and clay, sometimes stratified, but often wholly devoid of stratification, for a depth of more than a hundred feet. To this unstratified form of the deposit, the name of *till* has been applied in Scotland. It generally contains numerous fragments

of rocks, some angular and others rounded, which have been derived from formations of all ages, both fossiliferous, volcanic, and hypogene, and which have often been brought from great distances. Some of the travelled blocks are of enormous size, several feet or yards in diameter; their average dimensions increasing as we advance northwards. The till is almost everywhere devoid of organic remains, unless where these have been washed into it from older formations; so that it is chiefly from relative position that we must hope to derive a knowledge of its age.

Although a large proportion of the boulder deposit is made up of fragments brought from a distance, and which have sometimes travelled many hundred miles, the bulk of the mass in each locality consists of the ruins of subjacent or neighbouring rocks; so that it is red in a region of red sandstone, white in a chalk country, and grey or black in a district of coal and coal-shale.

Northern origin of erratics. — That the erratics of northern Europe have been carried southward, cannot be doubted; those of granite, for example, scattered over large districts of Russia and Poland, agree precisely in character with rocks of the mountains of Lapland and Finland; while the masses of gneiss, syenite, porphyry, and trap, strewed over the low sandy countries of Pomerania, Holstein, and Denmark, are identical in

mineral characters with the mountains of Norway and Sweden.

It is found to be a general rule in Russia, that the smaller blocks are carried to greater distances from their point of departure than the larger; the distance being sometimes 800 and even 1000 miles from the nearest rocks, from which they were broken off; the direction having been from N.W. to S.E., or from the Scandinavian mountains over the seas and low lands to the south-east.

When we have once ascertained that the main direction of the continuous stream of blocks was from Scandinavia towards more southern latitudes, and when we have traced it from Denmark across the Elbe, and through Westphalia, to the borders of Holland, we are the less surprised to find it reappear on our eastern coast, between the Tweed and the Thames, regions not half so remote from parts of Norway as are many Russian erratics from the sources whence they came. That its accumulation throughout this area took place wholly, or in great part, during the Post-Pliocene period is proved by its superposition at several points to strata containing recent shells. Thus, for example, in European Russia, M. M. Murchison and De Verneuil found, in 1840, that the flat country between St. Petersburgh and Archangel, for a distance of 600 miles, consisted of horizontal strata, full of shells similar to those

now inhabiting the arctic sea, on which rested the boulder formation, containing large erratics.

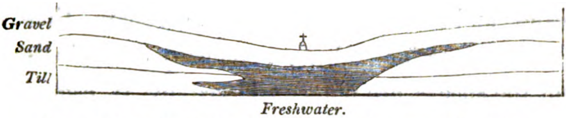
In Sweden, in the immediate neighbourhood of Upsala, I observed, in 1834, a ridge of stratified sand and gravel, in the midst of which is a layer of marl, evidently formed originally at the bottom of the Baltic, by the slow growth of the mussel, cockle, and other marine shells intermixed with some of fresh-water species. The marine shells are all of dwarfish size, like those now inhabiting the brackish waters of the Baltic; and the marl, in which myriads of them are imbedded, is now raised more than 100 feet above the level of the Gulf of Bothnia. Upon the top of this ridge repose several huge erratics, consisting of gneiss for the most part unrounded, from nine to sixteen feet in diameter, and which must have been brought into their present position since the time when the neighbouring gulf was already characterized by its peculiar fauna.* Here, therefore, we have proof that the transport of erratics continued to take place, not merely when the sea was inhabited by the existing testacea, but when the north of Europe had already assumed that remarkable feature of its physical geography, which causes the Gulf of Bothnia to have only one fourth of the saltness belonging to the ocean. In Denmark, also, recent shells have been found

* See paper by the author, Phil. Trans. 1835, p. 15.

in stratified beds, closely associated with the boulder clay.

Norfolk Drift. — The same association recurs in England, where the boulder deposit may be studied with the greatest advantage in the cliffs of the Norfolk coast, between Happisburgh and Cromer. Vertical sections, having an ordinary height of from 50 to 70 feet, are there exposed to view for a distance of about 20 miles. The name of diluvium was formerly given to it by those who supposed it to have been produced by the violent action of a sudden and transient deluge, but the term drift has been substituted by those who reject this hypothesis. Here, as elsewhere, it consists for the most part of clay, loam, and sand, in part stratified, in part devoid of stratification. Pebbles, together with some large boulders of granite, porphyry, greenstone, lias, chalk, and other transported rocks, are interspersed, especially through the till. White chalk rubble, unmixed with foreign matter, and even huge fragments of solid chalk, also occur in many localities. No fossils have been detected in this drift, which can positively be referred to the era of its accumulation; but at some points it overlies a freshwater formation containing recent shells, and at others it is blended with the same in such a manner as to force us to conclude that both were contemporaneously deposited.

Fig. 101.



Intercalation of the freshwater beds and boulder clay at Mundesley.

This interstratification is expressed in the annexed figure, the dark mass indicating the position of the freshwater beds, which contain much vegetable matter, and are divided into thin layers. The imbedded shells belong to the genera *Planorbis*, *Limnea*, *Paludina*, *Unio*, *Cyclas*, and others, all of British species, except a minute *Paludina* now inhabiting France. (See Fig. 102.)

Fig. 102.

Paludina marginata, Michaud. (*P. minuta*, Strickland.)
The middle figure is of the natural size.

The *Cyclas* (Fig. 103.) is merely a remarkable

Fig. 103.

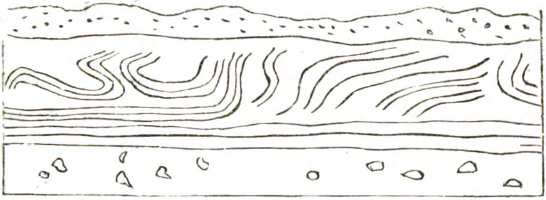
Cyclas (*Pisidium*) *amnica*, var. ?
The two middle figures are of the natural size.

variety of the common English species. The scales and teeth of fish of the genera Pike, Perch, Roach, and others, accompany these shells; but the species are not considered by M. Agassiz to be identical with known British or European kinds. If all the shells, therefore, of these freshwater beds, when more thoroughly investigated, should prove to be of recent species, the associated Norfolk drift must be referred to part of the Post-Pliocene period.

The series of formations in the cliffs of eastern Norfolk, now under consideration, beginning with the lowest, is as follows: — First, chalk; secondly, patches of a marine tertiary formation, called the Norwich Crag, hereafter to be described; thirdly, the freshwater beds already mentioned; and lastly, the drift. Immediately above the chalk, or crag, when that is present, is found here and there a buried forest, or a stratum in which the stools and roots of trees stand in their natural position, the trunks having been broken short off and imbedded with their branches and leaves. It is very remarkable that the strata of the overlying boulder formation have often undergone great derangement at points where the subjacent forest bed and chalk remain undisturbed. There are also cases where the upper portion of the boulder deposit has been greatly deranged, while the lower beds of the same have continued horizontal. Thus the an-

nexed section (Fig. 104.) represents a cliff about 50 feet high, at the bottom of which is *till*, or

Fig. 104.



Cliff 50 feet high between Bacton Gap and Mundesley.

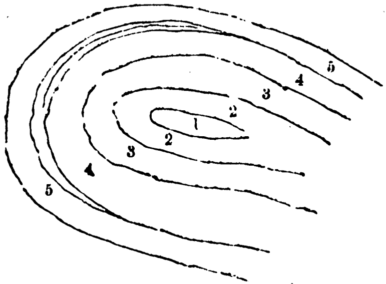
unstratified clay, containing boulders, having an even horizontal surface, on which repose conformably beds of laminated clay and sand about 5 feet thick, which, in their turn, are succeeded by vertical, bent, and contorted layers of sand and loam 20 feet thick, the whole being covered by flint gravel. Now the curves of the variously coloured beds of loose sand, loam, and pebbles are so complicated that not only may we sometimes find portions of them which maintain their verticality to a height of ten or fifteen feet, but they have also been folded upon themselves in such a manner that continuous layers might be thrice pierced in one perpendicular boring.

Fig. 105.

Folding of the strata between East and West Runton.

At some points there is an apparent folding of the beds round a central nucleus, as at *a*, Fig. 105., where the strata seem bent round a small mass of

Fig. 106.



Section of concentric beds west of Cromer.

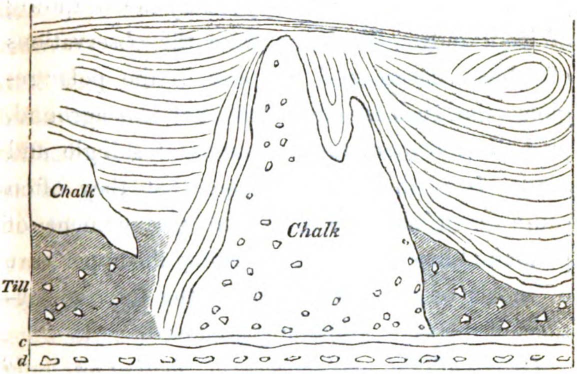
1. Blue clay. 3. Yellow sand.
2. White sand. 4. Striped loam and clay.
5. Laminated blue clay.

chalk; or, as in Fig. 106., where the blue clay, No. 1., is in the centre; and where the other strata, 2, 3, 4, 5, are coiled roun d it; the entire mass being 20 feet in perpendicular height. This appearance of concentric arrangement round a nucleus is, nevertheless, delusive, being produced by the intersection of beds bent into a convex shape; and that which seems the nucleus being, in fact, the innermost bed of the series, which has become partially visible by the removal of the protuberant portions of the outer layers.

To the north of Cromer are other fine illustrations of contorted drift reposing on a floor of chalk horizontally stratified and having a level surface. These phenomena, in themselves sufficiently difficult of explanation, are rendered still more anomalous by the occasional inclosure in the drift of huge fragments of chalk many yards in diameter. One striking instance occurs west of Sherringham, where an enormous pinnacle of

chalk, between 70 and 80 feet in height, is flanked on both sides by vertical layers of loam, clay, and gravel. (Fig. 107.)

Fig. 107.



Included pinnacle of chalk at Old Hythe point, west of Sherringham.

This chalky fragment is only one of many detached masses which have been included in the drift, and forced along with it into their present position. The level surface of the chalk *in situ* (*d*) may be traced for miles along the coast, where it has escaped the violent movements to which the incumbent drift has been exposed.*

We are called upon, then, to explain how any force can have been exerted against the upper masses, so as to produce movements in which the subjacent strata have not participated. It may

* For a full account of the drift of East Norfolk, see a paper by the author, Phil. Mag., No. 104., May, 1840.

be answered that, if we conceive the till and its boulders to have been drifted to their present place by ice, a theory in support of which many arguments will presently be adduced, the lateral pressure may have been supplied by the stranding of ice islands. We learn, from the observations of Messrs. Dease and Simpson in the polar regions, that such islands, when they run aground, push before them large mounds of shingle and sand. It is therefore probable that they often cause great alterations in the arrangement of pliant and incoherent strata forming the upper part of shoals or submerged banks, the inferior portions of the same remaining unmoved.

Origin of Till and agency of floating ice. — If we call to mind the descriptions given of icebergs by those who have explored the arctic circle, we shall find reason to believe that the till above alluded to, with its boulders, is just such a mass as might be looked for wherever earth and stones have fallen to the bottom of the sea from melting ice. Thus, an account was given in the year 1822, by Scoresby, of icebergs seen by him drifting along in latitudes 69° and 70° N., which rose above the surface from 100 to 200 feet, and measured from a few yards to a mile in circumference. Many of them were loaded with beds of earth and rock, of such thickness that the weight was

conjectured to be from 50,000 to 100,000 tons.*

A similar transportation of rocks is known to be in progress in the southern hemisphere. Thus an iceberg was encountered in 1839, in mid-ocean, in the antarctic regions, many hundred miles from any known land, sailing northwards, with a large erratic block firmly frozen into it.

The manner in which glaciers are formed in the mountainous regions of high latitudes, and become laden with mud and stones, will be mentioned in the next chapter. When they reach the sea, large masses become detached, and float off in the shape of icebergs. As these glaciers, when they fail to reach the sea-coast, leave at their extremity, wherever they melt away, a confused heap of unstratified rubbish, composed of mud and pieces of all the rocks with which they are loaded, so we may expect that the same kind of till may result from the liquefaction of icebergs in tranquil water. But, should the action of a current intervene at certain points or at certain seasons, then the materials will be sorted as they fall, and arranged in layers according to their relative weight and size. Hence there will be passages from till to stratified clay, gravel, and sand, and intercalations of one in the other.

It is not improbable, however, that a large

* Voyage in 1822, p. 233.

portion of the Norfolk till may have resulted from the melting of barrier ice; for we find that, on some coasts of the antarctic regions, innumerable ice islands are drifted into bays by winds and currents, where they remain motionless, and, for the most part, aground, for months or years. One of these icy barriers, lately observed on Enderby's Land, is described as being from ten to fifteen miles broad, and fragments of a great variety of rocks were collected on it. The partial melting of such stationary ice might give rise to a deposit wholly distinct from any which can be formed by running water alone. For the solid materials, some angular and others rounded, and the accompanying mud, may have been derived partly from adjacent lands, and even in that case from the glaciers of many independent hydrographical basins, and partly from points very remote, producing a mixture of the most heterogeneous nature. Of such a character is the till or boulder clay, not only of Norfolk and Suffolk, but also of parts of the counties of Essex, Cambridge, Huntingdon, Bedford, Hertford, and Middlesex. We find dispersed irregularly through it many angular and rounded stones, from fossiliferous rocks older than the coal, and from the Silurian and carboniferous strata, and from the lias, oolite, chalk, and London clay, all with their peculiar fossils, together with trap, syenite, mica-schist, and other igneous and crystalline rocks. A

fine example of this singular mixture may be seen almost in the suburbs of London, on the summit of Muswell Hill, near Highgate. Yet this deposit is partial, and is wanting in the Wealden district of Surrey, Kent, and Sussex. Perhaps it was only accumulated where the land was submerged during the epoch of floating ice; and this suggestion recals to our consideration the buried forest already adverted to as underlying the drift on the coast of Norfolk. At the time when the trees grew there must have been dry land over a large area, which was afterwards submerged, so as to allow a mass of stratified and unstratified drift, 200 feet and more in thickness, to be superimposed. The encroachments of the sea in recent times enable us to demonstrate, beyond all doubt, the fact of this superposition, and that the forest was not formed along the present coast-line. Its situation implies a subsidence of several hundred feet since the commencement of the Post-Pliocene period, after which there must have been an upheaval of the same ground; for the forest bed of Norfolk is now again so high as to be exposed to view at many points at low water; and this same upward movement may explain why the till, which is conceived to have been of submarine origin, is now met with far inland, and on the summit of hills.

The boulder formation of the west of England,

observed in Lancashire, Cheshire, Shropshire, Staffordshire, and Worcestershire, contains in some places marine shells of recent species, rising to various heights, from 100 to 350 feet above the sea. Here the erratics have come partly from the mountains of Cumberland, and partly from those of Scotland.

Boulder formation of Canada. — I shall conclude this chapter with remarking, that although the fossils of the European tertiary formations in general imply the former existence of warmer climates than those now experienced in the same latitudes, yet, at the close of the Pliocene and beginning of the Post-Pliocene periods, signs are not wanting in the northern hemisphere, both in Canada and Scotland, of the extension of an arctic climate farther southwards than in our own times. Some localities in Scotland, where the phenomena have been observed, will be alluded to in the next chapter. Among those in Canada may be mentioned Beauport, and other points near Quebec, where strata of sand and clay have been found by Capt. Bayfield, containing an assemblage of fossil shells, which agree much more nearly with those now inhabiting the arctic regions than with the assemblage living at present in the Gulf of St. Lawrence. The individuals are in great abundance, but the species few, as in very high latitudes; and, what is almost equally cha-

racteristic of polar regions, the genera are almost as numerous as the species. It is remarkable that, although so few shells are now common to both sides of the Atlantic, these fossils are specifically identical, for the most part, with shells met with in strata at Uddevalla, and other places in Sweden and Norway, situated between the latitudes 58° and 60° north; those of Canada being in latitude 47° north, or the same parallel as the mouth of the Loire in France. The American formation attains at Beauport and elsewhere a height of 200 and 300 feet above the sea, and contains dispersed through the strata large boulders of granite, which could not have been propelled by a violent current, because the accompanying fragile shells are almost all entire. They seem, therefore, says Captain Bayfield, to have been dropped down from melting ice, like similar stones which are now annually deposited in the St. Lawrence.* In that river the loose ice accumulates on the shoals during winter, at which season the water is low. The separate fragments are readily frozen together in a climate where the temperature is sometimes 30° below zero, and boulders become entangled with them, so that in the spring, when the river rises, on the melting of the snow, the packs are floated off, frequently

* Proceedings of Geol. Soc. No. 63. p. 119.

conveying away stones, several feet or even yards in diameter, to great distances. A single block of granite, 15 feet long, by 10 feet both in width and height, and which could not contain less than 1500 cubic feet of stone, was in this way moved down the river several hundred yards, during the late survey in 1837.* Heavy anchors of ships, lying on the shore, have, in like manner, been closed in and removed. In October, 1836, wooden stakes were driven several feet into the ground, at one point on the banks of the St. Lawrence, at high water mark, and over them were piled many boulders, as large as the united force of six men could roll. The year after, all the boulders had disappeared, and others had arrived, and the stakes had been drawn out and carried away by the ice.

It is also ascertained, that ice-islands, detached far to the north, perhaps in Baffin's Bay, are brought by the current, in great numbers, down the coast of Labrador, every year, and are often carried through the straits of Belle Isle, between Newfoundland and the continent of America. These, after passing through the straits, sometimes float for several hundred miles to the south-west, up the Gulf of St. Lawrence, between the 40th and 50th degrees of N. latitude. In one of

* See a view of this and many accompanying boulders, Plate IV., Principles of Geology, 6th ed.

these icebergs, heaps of boulders and gravel were seen.

That stones are annually moved by ice in the Baltic, has long been known; and, very recently, on the shores of the Gulf of Finland, some large fragments were ascertained to have been carried many yards from the spot which they had previously occupied. When the fringe of ice which has encircled, during winter, the coast of the Gulf of Bothnia, and many parts of Sweden, Norway, and Denmark, breaks up, in spring, large stones, with small gravel and ice, all firmly frozen together on the beach, are floated away in detached masses.

In the beginning of this chapter, it was stated that in Russia and Northern Germany the erratics diminish in size in proportion as they are traced farther from their source. The same observation holds true in regard to the average bulk of the Scandinavian boulders, when we pursue them southwards, from the south of Norway and Sweden through Denmark and Westphalia. This phenomenon is in perfect harmony with the theory of ice-islands floating in a sea of variable depth; for the heavier erratics require icebergs of a larger size to buoy them up; and, even when there are no stones frozen in, more than nine tenths of a mass of drift ice is under water. The greater, therefore, the volume of the iceberg, the sooner

would it impinge on some shallower part of the sea; while the smaller and lighter floes, laden with finer mud and gravel, may pass freely over the same banks, and be carried to much greater distances. In embracing this opinion, however, we are not called upon to imagine that the northern sea was of small depth at the time of the transportation of large erratics, — a notion inconsistent with the great height at which some of them are found above its level. An iceberg 200 or 300 feet high would run aground in water more than 1000 feet deep; and Captain Ross found this to be the case in Baffin's Bay, where several were seen stranded in water 1500 feet deep.

CHAPTER XI.

BOULDER FORMATION CONTINUED, AND LOESS OF THE RHINE.

Signs of former extension of glaciers in the Alps — Moraines — Grooved and polished surface of rocks — Arrangement of Alpine erratics on the Jura — Whether transported by glaciers or floating ice — Recent transportation of erratics from the Andes to Chiloe — Till and erratics of Scotland — Ridges of till, sand, and gravel — Arctic character of fossils above the till on Clyde — Parts of the boulder deposit older than others — Whether the general climate of the globe was colder when the Scandinavian and Alpine drift was formed — Loess of the Rhine containing land shells — Its supposed connection with the melting of the Alpine glaciers.

It has long been a favourite conjecture with those who have speculated on the origin of the boulder deposit, that it was produced by a violent flood, or great oceanic wave from the north, the course of the Scandinavian blocks to Russia and Germany, and those of Canada to the United States, showing that they have travelled from higher to lower latitudes in distant parts of the northern hemisphere. It is scarcely necessary to point out to the reader how perfectly the general fact above mentioned is in accordance with the theory advanced in the last chapter, that floating ice has been mainly instrumental in the transport of erra-

tics, inasmuch as the prevailing direction, both of icebergs and coast ice, is from polar to temperate latitudes.

The universality of large travelled fragments in all the countries bordering the Baltic, compared with their extreme rarity in those surrounding the Mediterranean, is another phenomenon confirmatory of the same views. It is also to be remarked, that true erratics are wanting in the equatorial parts of Asia, Africa, and America; whereas, when we cross the southern tropic, and reach Chili and Patagonia, we again encounter the boulder formation, between the latitude 41° S. and Cape Horn, with precisely the same characters which it assumes in Europe.

Alpine Erratics and Glaciers.—We have already seen that the ice of rivers, and that formed on coasts during winter, are very efficient as carrying powers; but the larger islands of ice which rise to the height of 200 or 300 feet above the surface, and which can only float in water of great depth, are neither formed on coasts nor in rivers, but are generated in inland valleys in the form of glaciers, which descend to the sea, and from which large portions break off and are drifted away by currents. Something, therefore, must be said in this place of glaciers; and, in treating of those in Switzerland, we shall be led on to the discussion of another question of high geological interest,

namely, the peculiar manner in which erratics have been dispersed from that chain, as a centre, over the lower lands of Switzerland, Italy, Austria, and France.

In the year 1821, M. Venetz first announced his opinion that the Alpine glaciers must formerly have extended far beyond their present limits, and the proofs appealed to by him in confirmation of this doctrine were afterwards acknowledged by M. Charpentier, who strengthened them by new observations and arguments, and declared, in 1836, his conviction that the glaciers of the Alps must once have reached as far as the Jura, and have carried thither their moraines across the great valley of Switzerland. M. Agassiz, after several excursions in the Alps with M. Charpentier, and after devoting himself some years to the study of glaciers, published, in 1840, an admirable description of them, and of the marks which attest the former action of great masses of ice over the entire surface of the Alps, and the surrounding country.* From his researches, and those of his predecessors, we learn that the glaciers which fill the Alpine valleys have in summer a slow downward motion, which is partly due to gravitation, and partly to the dilatation of the mass during the freezing of water infiltered into

* Agassiz, Études sur les Glaciers, of which an excellent analysis has been published in English by Mr. Maclaren.

pores and rents. The surface of the glacier is strewed over with gravel and stones detached from the surrounding precipices by frost, rain, lightning, or avalanches. Long lines of these stones, which settle on the sides of the glacier, are called the lateral moraines; while that found at the lower end of the ice is called the terminal moraine, a mass of earth and boulders, which it pushes before it when advancing, and leaves behind it when retreating; for when, in the Alps, a glacier reaches a lower and warmer situation, elevated about 3000 or 4000 feet above the sea, it melts so rapidly that, in spite of its downward movement, it can advance no farther. Its precise limits are variable from year to year, and still more so from century to century; one example being on record, of a recession of half a mile in a single year. We also learn from M. Venetz, that whereas, between the eleventh and fifteenth centuries, all the Alpine glaciers were less advanced than now, they began in the seventeenth and eighteenth centuries to push forward so as to cover roads formerly open, and to overwhelm forests of ancient growth.

These oscillations enable the geologist to note the marks which they leave behind them as they retrograde, and among these the most prominent are the terminal moraines, or mounds of unstratified earth and stones, often divided by subsequent floods into hillocks, which cross the valley like

ancient earth-works, or embankments made to dam up the river. Some of these transverse barriers were formerly pointed out by Saussure below the glacier of the Rhone, as proving how far it had once transgressed its present boundaries. On these moraines we see many large angular fragments, which, having been carried along on the surface of the ice, have not had their edges worn off by friction; but the greater number of the boulders, even those of large size, have been well-rounded, not by the power of water, but by the mechanical force of the ice, which has pushed them against each other, or against the rocks flanking the valley. Others have fallen down the numerous fissures which intersect the glacier, where, being subject to the pressure of the whole mass of ice, they have been forced along, and either well rounded or ground down into sand, or even the finest mud, of which the moraine is largely constituted.

As the terminal moraines are the most prominent of all the monuments left by a receding glacier, so are they the most liable to obliteration; for violent floods or debacles are often occasioned in the Alps by the sudden bursting of what are called glacier-lakes. These temporary sheets of water are caused by the damming up of a river by a glacier which has increased during a succession of cold seasons, and, descending from a tri-

butary into the main valley, has crossed it from side to side. On the failure of this icy barrier, the accumulated waters are let loose, which sweep away and level all transverse mounds of gravel and loose boulders below, and spread their materials in confused and irregular beds over the river-plain.

Another mark of the former action of glaciers, in situations where they exist no longer, is the polished, striated, or grooved surface of the rocks. The boulders, gravel, and sand, which lie underneath the glacier and are pushed along by it, sometimes adhere to the ice, and as the mass glides slowly along at the rate of a few inches, or at the utmost two or three feet, per day, they abrade, groove, and polish the rock, and the larger blocks are reciprocally grooved and polished by the rock on their lower sides. As the forces both of pressure and propulsion are enormous, the sand, acting like emery, polishes the surface; the pebbles, like coarse gravers, scratch and furrow it; and the large stones scoop out grooves in it.

Although the surface of almost every kind of rock, when exposed in the open air, wastes away by decomposition, yet some retain for ages their polished and furrowed exterior; and, if they are well protected by a covering of clay or turf, these marks of abrasion seem capable of enduring for

ever. They have been traced in the Alps to great heights above the present glaciers, and to great horizontal distances beyond them.

There are also found, on the sides of the Swiss valleys, round and deep holes, with polished sides, such holes as waterfalls make in the solid rock, but in places remote from running waters, and where the form of the surface will not permit us to suppose that any cascade could ever have existed. Similar cavities are common in hard rocks, such as gneiss, in Sweden, where they are called *giant caldrons*, and are sometimes ten feet and more in depth; but in the Alps and Jura they often pass into spoon-shaped excavations and prolonged gutters. We learn from M. Agassiz that hollows of this form are now cut out by streams of water, which flow along the surface of glaciers, and then fall into fissures which are open to the bottom. Here, forming a cascade, the stream cuts a round cavity in the rock with the gravel and sand which it either finds there or carries down with it; and, as it usually happens that the glacier is advancing, a locomotive cascade is produced, which converts the first circular hole into a deep groove.

Another effect of a glacier is to lodge a ring of stones round the summit of a conical peak which may happen to project through the ice. If the glacier is lowered greatly by melting, these circles of large angular fragments, which are called

"perched blocks," are left in a singular situation near the top of a steep hill or pinnacle, the lower parts of which may be destitute of boulders.

Alpine blocks on the Jura.—Now some or all the marks above enumerated,—the moraines, erratics, polished surfaces, striæ, caldrons, and perched rocks, are observed in the Alps at great heights above the present glaciers, and far below their actual extremities, also in the great valley of Switzerland, fifty-miles broad, and almost everywhere on the Jura, a chain which lies to the north of this valley. The average height of the Jura is about one third that of the Alps, and is now entirely destitute of glaciers, yet it presents almost everywhere similar moraines, and the same polished and grooved surfaces, and water-worn cavities. The erratics, moreover, which cover it, present a phenomenon which has astonished and perplexed the geologist for more than half a century. No conclusion can be more incontestible than that these angular blocks of granite, gneiss, and other crystalline formations, came from the Alps, and that they have been brought for a distance of fifty miles and upwards across one of the widest and deepest valleys of the world, so that they are now lodged on the hills and valleys of a chain composed of limestone and other formations, altogether distinct from those of the Alps. Their great size and angularity, after

a journey of so many leagues, has justly excited wonder; for hundreds of them are as large as cottages; and one in particular, celebrated under the name of Pierre à Bot, rests on the side of a hill about 900 feet above the lake of Neufchatel, and is no less than forty feet in diameter.

Von Buch, Escher, and Studer have shown, from an examination of the mineral composition of the boulders, that those on the western Jura, near Neufchatel, have come from the region of Mont Blanc and the Valais; those on the middle parts of the Jura from the Bernese Overland; and those on the eastern Jura from the Alps of the small cantons, Glaris, Schwytz, Uri, and Zug. The blocks, therefore, of these three great districts have been derived from parts of the Alps nearest to the localities in the Jura where we now find them, as if they had crossed the great valley in a direction at right angles to its length: the most western stream having followed the course of the Rhone, the central, that of the Aar, and the eastern, that of the two great rivers, Reuss and Limmat. The non-intermixture of these groups of travelled fragments, except near their confines, was always regarded as most enigmatical by those who adopted the opinion of Saussure, that they were all whirled along by a rapid current of muddy water rushing from the Alps.

M. Charpentier first suggested, as before men-

tioned, that the Swiss glaciers once reached continuously to the Jura, and conveyed to them these erratics; but at the same time he conceived that the Alps were formerly higher than now. M. Agassiz, on the other hand, instead of introducing distinct and separate glaciers, imagines that the whole valley of Switzerland was filled with ice, and that one great sheet of it extended from the Alps to the Jura, when the two chains were of the same height as now relatively to each other. Such an hypothesis labours under this difficulty, that the difference of altitude, when distributed over a space of fifty miles, gives an inclination of no more than two degrees, or far less than that of any known glaciers.

In the theory which I formerly advocated in the Principles of Geology, and which jointly with Mr. Darwin I have since endeavoured to render more complete, it was suggested that the erratics may have been transferred by floating ice to the Jura, at the time when the greater part of that chain, and the whole of the Swiss valley to the south, was under the sea. At that period the Alps may have attained only half their present altitude, and may yet have constituted a chain as lofty as the Chilian Andes, which, in a latitude corresponding to Switzerland, now send down glaciers to the head of every sound, from which icebergs, covered with blocks of granite, are

floated seaward.* Opposite that part of Chili where the glaciers abound is situated the island of Chiloe, 100 miles in length, with a breadth of 30, running parallel to the continent. The channel which separates it from the main land is of considerable depth, and twenty-five miles broad. Parts of its surface, like the adjacent coast of Chili, is overspread with recent marine shells, showing an upheaval of the land during a very modern period; and beneath these shells is a boulder deposit, in which Mr. Darwin found large travelled blocks. One group of fragments were of granite, which had evidently come from the Andes, while in another place angular blocks of syenite were met with. Their arrangement may have been due to successive crops of icebergs issuing from different sounds, to the heads of which glaciers descend from the Andes. These icebergs, taking their departure year after year from distinct points, may have been stranded repeatedly, in equally distinct groups, in bays or creeks of Chiloe, and on islets off the coast, so as afterwards to appear, some on hills and others in valleys, when that country and the bed of the adjacent sea had been upheaved. A continuance in future of the elevatory movement, in the region of the Andes and of Chiloe, might cause the former chain to rival the Alps in altitude, and

* Darwin's Journal, p. 283.

give to Chiloe a height equal to that of the Jura. The same rise might dry up the channel between Chiloe and the main land, so that it would then represent the great valley of Switzerland. In the course of these changes, all parts of Chiloe and the intervening strait, having in their turn been a sea-shore, may have been polished and scratched by innumerable icebergs running aground and grating on the bottom.

If we apply this hypothesis to Switzerland and the Jura, we are by no means precluded from the supposition that, in proportion as the land acquired additional height, and the bed of the sea emerged, the Jura itself may have had its glaciers; and those existing in the Alps, which had at first extended to the sea, may, during some part of the period of upheaval, have been prolonged much farther into the valleys than now. At a later period, when the climate grew milder, these glaciers may have entirely disappeared from the Jura, and may have receded in the Alps to their present limits, leaving behind them in both districts those moraines which now attest the former extension of the ice.

It must be confessed, that our never having yet discovered marine shells of Recent or Pliocene species in the great valley of Switzerland or the Jura presents a formidable objection to the views above set forth, no marine tertiary strata newer

than the Miocene having yet been detected between the Alps and Jura; and the shells and corals of the Miocene period implying a warmer climate than would seem compatible with the prevalence of so much ice in Europe.

Boulder deposit of Scotland.—On the other hand, daily experience teaches us to attach less and less importance to this kind of negative evidence in geology. Thus the like absence of organic remains has been remarked in the boulder formation, especially in the till, throughout Scotland; the only exceptions being the tusks and bones of the mammoth, found with a few marine shells in the till of Ayrshire. The same remark holds good in regard to the Scandinavian and Norfolk drift, although capable of preserving those fossils which are washed into it from older rocks. The rarity or entire want of fossil remains in these cases may be due to one or all of the following causes: First, as there are no shells in the moraines of glaciers, there will be none in the materials falling from melting icebergs; Secondly, as the stranding of ice-islands in the bays of Iceland since 1835 has driven away the fish for several successive seasons, and thereby caused a famine among the inhabitants of the coast, so we may presume that a sea habitually infested with melting ice, which would chill and *freshen* the water, might render the same uninhabitable by *marine* mollusca; Thirdly, parts of the boulder formation

which are stratified are probably due to river-floods; and the gravel and sand brought down by these inundations would scarcely ever contain organic remains, or, if so, would be too porous to retain them.

When we endeavour to account for the boulder deposit of Scotland, we meet with many of the same difficulties as in Switzerland. Thus, for example, north of the Tay, in Forfarshire, we may compare the Grampians, rising to the height of 4000 feet and more, to the Alps; the valley of Strathmore to the Pays de Vaud, and the Sidlaw Hills to the Jura.* On the Sidlaw Hills we find large angular fragments of mica-schist, from 3 to 15 feet in diameter, at various heights; some ascending even to the highest summit, 1500 feet above the sea, and 15 miles distant from the nearest Grampian from which they could have been detached. In the large intervening vale of Strathmore, till, from 20 to 100 feet deep, and full of Grampian boulders, conceals almost every where the subjacent secondary rocks. If we then ascend into the region of the Grampians, we find in every glen longitudinal and frequently transverse mounds, like the lateral and terminal moraines of Swiss glaciers. The detritus in these mountains has everywhere a local character, and as we trace it downwards it becomes more complex in its composition, in proportion as it re-

* See section, p. 103.

ceives the contribution of a greater number of lateral glens.

From these and other appearances, we may infer the probable existence of glaciers at that period when erratics were dispersed from the Grampians as from a centre over the surrounding regions. But in Scotland the submergence of the lower country, and the co-operation of floating ice, seem more indispensable than in the case of Switzerland; for the points from which the Grampian boulders have been conveyed are much lower, and those to which they have been carried equally remote. One fragment of mica-schist, weighing from 8 to 10 tons, has been pointed out by Mr. Maclaren as occurring at the height of 1100 feet above the sea on the Pentland Hills; the nearest mountain composed of this formation being 50 miles distant.*

In the valley of Strathmore, and other low grounds in Perthshire and Forfarshire, long ridges of till, capped with stratified sand and gravel, from 50 to 70 feet high, may be traced for many leagues, often resembling in form the lateral moraines of glaciers. As in the Norfolk drift, before described, the uppermost strata have been often bent and folded, as if by lateral pressure, while those below remain horizontal. Several ridges are sometimes seen parallel to each other; and

* Geol. of Fife, &c., p. 220.

they wind like rivers, sometimes inclosing oval and quadrangular spaces, in which are peat mosses and lakes containing shell-marl. As these mounds, having a steep talus on both sides, are not confined to Highland glens, but may be followed for great distances over level plains, they may, perhaps, mark the ancient course of one or more rivers during the glacial period, on the banks of which sand, pebbles, and boulders were heaped up during floods, as is now observed in some of the rivers in the north of Russia. Thus, on the Dwina, 80 miles above Archangel, M. M. Murchison and De Verneuil met with a ridge of large angular blocks of white limestone piled up on the river's edge, and about 20 or 30 feet above the stream. They ascertained that this great river was periodically subject to occasional extraordinary rises in the spring, and that, on those occasions, it bursts, and throws up upon its banks blocks of ice to heights of 20 or 30 feet above its ordinary level. In illustration of the same subject, Mr. Böttlingk, of Dorpat, mentions that when the floods subside in the rivers of Russian Finland, they sometimes leave large stones, which had been buoyed up by ice, entangled in the branches of fir-trees, 40 feet above the ground. The muddy waters may also throw down layers of fine sediment on these same banks, and these may be frequently bent and forced into a vertical

position by the pressure of sheets of ice, as above explained (p. 232.).

It was stated that the boulder deposit of Russia reposed on strata containing recent marine shells (p. 224.); but the till in Scotland rests immediately on the older rocks, and is covered by stratified sand and clay, which usually contain no fossils. At certain points, however, near the sea coast, as, for example, in the estuaries of the Tay and Clyde, marine shells have been discovered in strata overlying the till. They occur on the Clyde at the height of 70 feet; but the deposit of which they form an integral part rises in the same country to an elevation of several hundred feet. Although between 80 and 90 per cent. are of recent species, the remainder are unknown; and even many which are recent now inhabit more northern seas, where we may hereafter hope to find living representatives of some of the unknown fossils. From the arctic character of this fauna, which resembles that of Quebec, before described, we may infer that these strata and the subjacent till are of higher antiquity than some parts of the boulder deposit of northern Europe. With respect, indeed, to the European drift and erratics in general, it is fair to presume that those parts of it are the most ancient which lie at present in regions most remote from existing glaciers and icebergs. The retreat of the

ice from the fifty-fifth to the eightieth parallel of latitude, or from Scotland to Spitzbergen, may well have been the work of time; and, during a period of considerable duration, it is consistent with geological analogy to look for signs of fluctuations in the state of the animate world. Nevertheless, it is probable that the action of river-ice continued in Scotland long after that of icebergs and glaciers had ceased; we may at least infer that the ridges of sand and boulders, which have been described as inclosing the marl-lakes of Perthshire and Forfarshire, were referable to the Post-Pliocene period. For the fossils in the marl, whether they be the remains of plants, testacea, or quadrupeds, belong to recent species which now inhabit Scotland, or which, like the beaver, have been exterminated in historical times. These fossils are found to the very bottom of the deposit, and clearly indicate the fauna which began to exist the moment after the present configuration of the surface was completed.

Climate of the glacial period. — M. Agassiz imagines that the signs of glacial action, traceable throughout the Alps and northern Europe, imply a more intense cold in the general climate of the globe than that now prevailing. That the cold was greater in certain parts of Siberia, Europe, and North America, will not be disputed; but, before we can infer the universality of a colder

climate, we must ascertain what was the condition of other parts of the northern, and of the whole southern, hemisphere at the time when the Scandinavian, British, and Alpine erratics were transported into their present position. It must not be forgotten that a great deposit of drift and erratic blocks is now in full progress of formation in the southern hemisphere, in a zone corresponding in latitude to the Baltic and to Northern Italy, Switzerland, France, and England. Should the uneven bed of the southern ocean be hereafter converted by upheaval into land, the hills and valleys will be strewed over with transported fragments, some derived from the antarctic continent, others from islands covered with glaciers, like S. Georgia, which must now be centres of the dispersion of drift, although situated in a latitude agreeing with that of the Cumberland mountains.

Not only are these operations going on between the 45th and 60th parallels of latitude south of the line, while the corresponding zone of Europe is free from ice; but, what is still more worthy of remark, we find in the southern hemisphere itself, only 900 miles distant from South Georgia, where the perpetual snow reaches to the sea-beach, lands covered with forests, as in Terra del Fuego. There is here no difference of latitude to account for the luxuriance of vegetation in one spot, and the absolute want of it in the other; but among other

refrigerating causes in South Georgia may be enumerated the countless icebergs which float from the antarctic zone, and which chill as they melt the waters of the ocean, and the surrounding air, which they fill with dense fogs.

I have endeavoured in the "Principles of Geology" to point out the intimate connexion of climate with the state of the physical geography of the globe, and the dependence of the mean annual temperature, not only on the height of the dry land, but on its distribution in high or low latitudes at particular epochs. If, for example, at certain periods of the past, the antarctic land was less elevated and less extensive than now, while that at the north pole was higher and more continuous, the conditions of the northern and southern hemispheres might have been the reverse of what we now witness in regard to climate, although the mountains of Scandinavia, Scotland, and Switzerland may have been less elevated than at present. But, as it would require several chapters to do justice to this subject, I must refer the reader to the work alluded to for the theory of former vicissitudes in climate; and also for an explanation of the manner in which the bones of the mammoth and rhinoceros may have been buried by thousands in the frozen soil and drift of Siberia.

Loess of the valley of the Rhine. — Although we may withhold our assent to the theory that the

erratic blocks of the Jura were conveyed from the Alps by ice moving on dry land, we must nevertheless admit that the Alpine glaciers once extended far beyond their present limits; and accordingly M. Agassiz has advanced the ingenious and not improbable conjecture that the loess of the Rhine, filled as it is with land and freshwater shells, may be referred to inundations caused by the melting and retreat of those great bodies of ice. This *loess*, as it is provincially termed in part of Germany, or *lehm*, as it is called in Alsace, consists chiefly of argillaceous matter combined with a sixth part of carbonate of lime, and a sixth of quartzose and micaceous sand. It is a pulverulent loam, of a dirty yellowish-grey colour, often containing calcareous sandy concretions or nodules, rarely exceeding the size of a man's head. Its entire thickness amounts, in some places, to between 200 and 300 feet; yet there are often no signs of stratification in the mass, except here and there at the bottom, where there is occasionally a slight intermixture of drifted materials derived from subjacent rocks.

This finely comminuted mud is very similar to that now formed by the grinding down of stones beneath the weight of the moving glaciers, and the loess is precisely such a compound as the trituration of the micaceous tertiary sand called "molasse" would produce; a circumstance worthy

of notice, as we may trace the loess continuously from the plains of the Rhine, below Cologne, up to the borders of Switzerland, until we enter the country occupied by the molasse, which the Alpine glaciers are supposed formerly to have reached. The deposit in question is very remarkable from its position, wide extent, and thickness, its homogeneous mineral character, and from its containing everywhere land and freshwater shells, without any intermixture of marine fossils. Its distribution clearly shows, that after the great valley of the Rhine, from Schaffhausen to Bonn, had acquired its present form, having its bottom strewed over with coarse gravel, a period arrived when it became filled up from side to side with fine mud, which was also poured from the Rhine into the valleys of its principal tributaries.

Thus, for example, it may be traced far into Würtemberg, up the valley of the Neckar; and from Frankfort, up the valley of the Main, to above Dettelbach. It is also spread over the country of Mayence, Eppelsheim, and Worms, on the left bank of the Rhine, and on the opposite side on the table land above the Bergstrasse, between Wiesloch and Bruchsal, where it attains a thickness of 200 feet. Near Strasburg, large masses of it are seen at the foot of the Vosges on the left bank, and at the base of the mountains of the Black Forest on the right bank. The Kaiser-

stuhl, a volcanic mountain which stands in the middle of the plain of the Rhine near Freiburg, has been covered almost everywhere with this loam, as have the extinct volcanos between Coblentz and Bonn. Near Andernach, in the Kirchweg, the loess containing the usual shells alternates with volcanic matter; and over the whole are strewed layers of pumice, lapilli, and volcanic sand, from 10 to 15 feet thick, very much resembling the ejections under which Pompeii lies buried. There is no passage at this upper junction from the loess into the pumiceous superstratum; and this last follows the slope of the hill, just as it would have done had it fallen in showers from the air on a declivity partly formed of loess.

But, in general, the loess overlies all the volcanic products, even those between Neuwied and Bonn, which have the most modern aspect; and it has filled up in part the crater of the Roderberg, an extinct volcano near Bonn. In 1833 a well was sunk at the bottom of this crater, through 70 feet of loess, in part of which were the usual calcareous concretions.

The interstratification above alluded to, of loess with layers of pumice and volcanic ashes, has led to the opinion that both during and since its deposition some of the last volcanic eruptions of the Lower Eifel have taken place. But as we must,

in that case, assign a very modern date to these eruptions, this curious point deserves to be reconsidered; since it may possibly have happened that the waters of the Rhine, swollen by the melting of snow and ice, and flowing at a great height through a valley choked up with loess, may have swept away the loose superficial scoriæ and pumice of the Eifel volcanos, and spread them out occasionally over the yellow loam. Sometimes, also, the melting of snow on the slope of small volcanic cones may have given rise to local floods, capable of sweeping down light pumice into the adjacent low grounds.

The first idea which has occurred to most geologists, after examining the loess between Mayence and Basle, is, to imagine that a great lake once extended throughout the valley of the Rhine between those two places. Such a lake may have sent off large branches up the course of the Main, Neckar, and other tributary valleys, in all of which large patches of loess are now seen. The barrier of the lake might be placed somewhere in the narrow and picturesque gorge of the Rhine between Bingen and Bonn. But this theory is insufficient to explain the phenomena; for that gorge itself has once been filled with loess, which must have been tranquilly deposited in it, as also in the lateral valley of the Lahn, communicating with the gorge. The loess has also overspread the

high adjoining platform near the village of Plaidt above Andernach. Nay, on proceeding farther down to the north, we discover that the hills which skirt the valley between Bonn and Cologne have loess on their flanks, which also covers here and there the gravel of the plain as far as Cologne.

Besides these objections to the lake theory, the loess is met with near Basle, capping hills more than 1200 feet above the sea; so that a barrier of land capable of separating the supposed lake from the ocean would require to be, at least, as high as the mountains called the Siebengebirge, near Bonn, the loftiest summit of which, the Oehlberg, is 1209 feet above the Rhine and 1369 feet above the sea. It would be necessary, moreover, to place this lofty barrier somewhere below Cologne, or precisely where the level of the land is now lowest.

Instead, therefore, of supposing one continuous lake of sufficient extent and depth to allow of the simultaneous accumulation of the loess, at various heights, throughout the whole area where it now occurs, I formerly suggested that, subsequently to the period when the countries now drained by the Rhine and its tributaries had nearly acquired their actual form and geographical features, they were again depressed gradually by a movement like that now in progress on the west coast of Greenland.* In proportion as the whole district was

* Princ. of Geol. 5th and preceding editions.

lowered, the general fall of the waters between the Alps and the ocean was lessened; and both the main and lateral valleys, becoming more subject to river inundations, were partially filled up with fluviatile silt, containing land and freshwater shells. When a thickness of many hundred feet of loess had been thrown down slowly by this operation, the whole region was once more upheaved gradually. During this upward movement most of the fine loam would be carried off by the denuding power of rains and rivers; and thus the original valleys might have been re-excavated, and the country almost restored to its pristine state, with the exception of some masses and patches of loess such as still remain, and which, by their frequency and remarkable homogeneousness of composition and fossils, attest the ancient continuity and common origin of the whole. By imagining these oscillations of level, we might dispense with the necessity of erecting and afterwards removing a mountain barrier almost sufficiently high to exclude the ocean from the valley of the Rhine during the period of the accumulation of the loess.

But, by adopting the glacial hypothesis, we escape from the necessity of assuming, not only the removal of a barrier, but also a great subsidence, followed by a re-elevation of the land, changes which, although consistent with the ordinary course of nature, are not as yet confirmed,

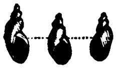
in this case, by independent evidence. If we once admit the former existence of large masses of ice, stretching from the sources of the Rhine into the great valley of Switzerland, we cannot doubt that the liquefaction of the same might have given rise for centuries to annual inundations, and that the water would be densely charged with the most impalpable mud, derived from the moraines of the retreating glaciers. The bottoms of every inundated valley would gradually gain in height by fresh accessions of the fine sediment, until its thickness might amount to several hundred feet. But a time would at length arrive when the supply of mud growing less, the waters, as they abated, would again hollow out the larger part of the original valley.

Besides the occasional proofs of successive accumulation afforded by interstratified gravel or volcanic matter, the calcareous concretions contained in the loess are sometimes arranged in horizontal layers. But the deposit exhibits for the most part no division into strata; and this characteristic of the loess must be attributed to the perfect homogeneousness of the matter thrown down from time to time, the whole mass having originated in one and the same region.

The proportion of land shells of the genera *Helix*, *Pupa*, and *Bulimus*, is very large in the loess; but in many places aquatic species of the genera

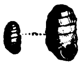
Limnea, *Paludina*, and *Planorbis* are also found. These may have been carried away during floods from shallow pools and marshes bordering the river, and the great extent of marshy ground caused by the wide overflowings of rivers above supposed would favour the multiplication of amphibious mollusks, such as the *Succinea* (Fig. 108.), which is almost everywhere characteristic of this

Fig. 108.



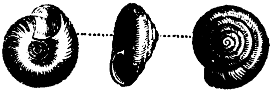
Succinea elongata.

Fig. 109.



Pupa muscorum.

Fig. 110.



Helix plebeium.

formation, and is sometimes accompanied, as near Bonn, by another species, *S. amphibia.* (Fig. 34.) Among other abundant fossils are *Helix plebeium* and *Pupa muscorum.* (See Figures.) Both the terrestrial and aquatic shells preserved in the loess are of most fragile and delicate structure, and yet they are almost invariably perfect and uninjured. They must have been broken to pieces had they been swept along by a violent inundation. Even the colour of some of the land shells, as that of *Helix nemoralis*, is occasionally preserved.

Bones of vertebrated animals are rare in the loess, but those of the mammoth, horse, and some other quadrupeds have been met with. At the village of Binningen, and the hills called Bruder

Holz, near Basle, I found the vertebræ of fish, together with the usual shells. These vertebræ, according to M. Agassiz, belong decidedly to the Shark family, perhaps to the genus *Lamna*. In explanation of their occurrence among land and fresh-water shells, it may be stated that certain fish of this family ascend the Senegal, Amazon, and other great rivers, to the distance of several hundred miles from the ocean.*

If the views above proposed respecting the origin of the loess be correct, we should expect to see analogous deposits along the course of other great rivers descending from the Alps; and accordingly such a deposit is said to occur on the banks of the Danube, as far as Hungary.

All the shells in the loess of the Rhine are of recent European species, so that the gradual filling up and re-excavation of the valleys of one of the largest hydrographical basins of Europe, an operation which must have consumed a long period of time, belongs to the modern or Post-Pliocene era; and the recession of the Alpine glaciers was, consistently with the hypothesis before suggested, a contemporaneous event.

* Proceedings Geol. Soc. No. 43. p. 222.

CHAPTER XII.

CLASSIFICATION OF TERTIARY FORMATIONS.

First discovery of tertiary strata — Detached formations scattered over Europe — Strata of Paris and London — More modern groups — General principles of classification — Peculiar difficulties in determining the chronology of tertiary groups — Increasing proportion of living species of shells in strata of newer origin — Terms Eocene, Miocene, and Pliocene — Percentage of recent species in the tertiary formations of Great Britain — Changes of climate at successive periods.

We come now to the consideration of a class of fossiliferous formations, called "tertiary" which are immediately antecedent in the order of time to the Post-Pliocene deposits already treated of. The name of tertiary has been given to them, because they are all posterior in date to the rocks termed "secondary," of which the chalk constitutes the newest group.

Patches of tertiary strata, some of freshwater, others of marine origin, have been observed in various parts of Europe, their geographical extent being usually small as compared to the secondary formations, and their position often suggesting the idea of their having been deposited in different bays, lakes, estuaries, or inland seas, after a large

portion of the European area had already been converted into dry land. They all agree in containing organic remains, which make upon the whole a nearer approach to the generic and specific types of the living creation, than do the fossils of the secondary rocks.

The first series of tertiary deposits of which the characters were accurately determined, were those occurring in the neighbourhood of Paris, first described by MM. Cuvier and Brongniart. They were ascertained to consist of successive sets of strata, some of marine, others of freshwater origin lying one upon the other. The fossil shells and corals were perceived to be almost all of unknown species, and to have in general a near affinity to those now inhabiting warmer seas. The bones and skeletons of land animals, some of them of large size, and belonging to more than forty distinct species, were examined by Cuvier, and declared by him not to agree with any hitherto observed in the living creation.

Strata were soon afterwards brought to light in the vicinity of London, and in Hampshire, which, although dissimilar in mineral composition were justly inferred by Mr. T. Webster to be of the same age as those of Paris, because the greater number of the shells were specifically identical. For the same reason rocks found on the Gironde, in the South of France, and at certain points in

the North of Italy, were suspected to be of contemporaneous origin.

A variety of deposits were afterwards found in other parts of Europe, all reposing immediately on rocks as old, or older than the chalk, and which bore a general resemblance in their organic remains to those previously observed near Paris and London. An attempt was therefore made at first to refer the whole to one period; and when at length this seemed impracticable, it was contended that as in the Parisian series there were many subordinate formations of considerable thickness which must have accumulated one after the other, during a great lapse of time, so the newly found patches of tertiary strata scattered over Europe might correspond in age, some of them to the older, and others to the newer subdivisions, of the Parisian series.

This error, although almost unavoidable on the part of those who made the first generalizations in this branch of geology, retarded seriously for some years the progress of classification. A more scrupulous attention to specific distinctions aided by a careful regard to the relative position of the strata containing them, led at length to the conviction that there were formations both marine and freshwater of various ages, and all newer than the strata of Paris and London.

One of the first steps in this chronological reform

was made in 1811, by an English naturalist, Mr. Parkinson, who pointed out the fact that certain shelly strata, provincially termed "Crag" in Suffolk, lay decidedly over a deposit which was the continuation of the blue clay of London. At the same time he remarked that the fossil testacea in these newer beds were not only distinct from those of the blue clay, but were many of them identical with species now inhabiting the neighbouring sea.

Another important discovery was soon afterwards made by Brocchi in Italy, who investigated the argillaceous and sandy deposits replete with shells which form a low range of hills, flanking the Apennines on both sides, from the plains of the Po to Calabria. These lower hills were called by him the Subapennines, and they contained in truth strata of very different ages, comprising even some beds which have been termed Post-Pliocene in the ninth chapter, but all were newer than those of Paris and London. In Brocchi's opinion about half the species of Subapennine shells agreed with those now living in the sea, an average result obtained from the fossils of the various members of the series which he had blended together.

Another tertiary group occurring in the neighbourhood of Bordeaux and Dax, in the S. of France, was examined by M. de Basterot in 1825, who described and figured several hundred

species of shells, which differed for the most part both from the Parisian series and those of the Subapennine hills. It was soon, therefore, suspected that this fauna might belong to a period intermediate between that of the Parisian and Subapennine strata, and it was not long before the evidence of superposition was brought to bear in support of this opinion, for other strata, contemporaneous with those of Bordeaux, were observed in one district to overlie the Parisian formation, and in another to underlie the Subapennine beds. An example of the former kind was pointed out in 1829 by M. Desnoyers, who ascertained that the sand and marl of marine origin called Faluns, near Tours, in the basin of the Loire, rested upon a lacustrine formation, which constitutes the uppermost subdivision of the Parisian group, extending continuously throughout a great table land intervening between the basin of the Seine and that of the Loire. These overlying strata, full of sea-shells and corals, M. Desnoyers assimilated in age to the Crag of Suffolk, before mentioned.* The other example occurs in Piedmont, where strata, containing many fossils similar to those of Bordeaux, were observed by Bonelli and others in the environs of Turin, subjacent to strata belonging to the Subapennine group of Brocchi.

* See chap. XIV.

Without pretending to give a complete sketch of the progress of discovery, I may refer to the facts above enumerated, as illustrating the course usually pursued by geologists when they attempt to found new chronological divisions. The method bears some analogy to that pursued by the naturalist in the construction of genera, when he selects a typical species, and then classes all other species of animals and plants which agree with this standard within certain limits as congeners. The genera A. and C. having been founded on these principles, a new species is afterwards met with, departing widely both from A. and C., but in many respects of an intermediate character. For this new type it becomes necessary to institute the new genus B., in which are included all species afterwards brought to light, which agree more nearly with B. than with the types of A. or C. In like manner a new formation is met with in geology, and the characters of its fossil fauna and flora investigated. From that moment it is considered as a record of a certain period of the earth's history, and a standard to which other deposits may be compared; and if they occupy the same relative position, and contain the same or nearly the same organic remains, they are regarded in the light of contemporary annals. All such monuments are said to relate to one period, during which certain events occurred, such as the

formation of particular rocks by aqueous or volcanic agency, or the continued existence and fossilization of certain tribes of animals and plants. When several of these periods have had their true places assigned to them in a chronological series, others may be discovered which it may be necessary to intercalate between those first known; and the difficulty of assigning clear lines of separation must increase in proportion as chasms in the past history of the globe are filled up.

Every zoologist and botanist is aware that it is a comparatively easy task to establish genera in departments which have been enriched with only a small number of species, and where there is as yet no tendency in one set of characters to pass almost insensibly, by a multitude of connecting links, into another. They also know that the difficulty of classification augments, and that the artificial nature of their divisions becomes more apparent in proportion to the increased number of objects brought to light. But in separating families and genera, they have no other alternative than to avail themselves of such breaks as still remain, or of every hiatus in the chain of animated beings which is not yet filled up. So in geology, we may be eventually compelled to resort to sections of time as arbitrary, and as purely conventional, as those which divide the history of human events into centuries. But in the present

state of our knowledge, it is more convenient to use the interruptions which still occur in the regular sequence of geological monuments, as boundary lines between our principal groups or periods.

The isolated position of distinct tertiary deposits in different parts of Europe has been already alluded to. In addition to the difficulty presented by this want of continuity when we endeavour to settle the chronological relations of these deposits, another arises from the frequent dissimilarity in mineral character of strata of contemporaneous date, such, for example, as those of London and Paris before mentioned. The identity or non-identity of species is also a criterion which often fails us. For this we might have been prepared, for we have already seen, that the Mediterranean and Red Sea, although so near each other, have each their peculiar fauna, and a considerable difference is found in the four groups of testacea now living in the Baltic, English Channel, Black Sea, and Mediterranean, although all these seas have some species in common. In like manner the diversity of the fossils of different tertiary formations, which have been thrown down in distinct seas, estuaries, bays, and lakes, does not always imply a distinctness in the times when they were produced, but may have arisen from climate and conditions of physical geography wholly inde-

pendent of time. On the other hand, it is perfectly clear, that different sets of tertiary strata immediately superimposed upon each other, contain distinct imbedded species of fossils, in consequence of fluctuations which have been going on in the animate creation, and by which in the course of ages one state of things in the organic world has been substituted for another wholly dissimilar. It has also been shown that in proportion as the age of a tertiary deposit is more modern, so is its fauna more analogous to that now in being in the neighbouring seas. It is this law of a nearer agreement of the fossil testacea with the species now living, which may often furnish us with a clue for the chronological arrangement of scattered deposits, where we cannot avail ourselves of any one of the three ordinary chronological tests; namely, superposition, mineral character, and the specific identity of the fossils.

Thus, for example, on the African border of the Red Sea, a white calcareous formation has been observed, containing several hundred species of shells differing from those found in the clay and volcanic tuff of Ischia, near Naples. Another deposit has been found at Uddevalla, in Sweden, in which a large portion of the shells do not agree with those of Ischia. But although in these three cases there may be scarcely a single shell common to the different formations, we do not

hesitate to refer them all to one period (the Post-Pliocene), because the species agree in every instance with those now living in the contiguous seas. In like manner, when we have discovered a limestone in Sicily, rising to the height of 3000 feet, in which more than four-fifths of the shells are the same as those of the Mediterranean, we may regard such a deposit as contemporaneous with other strata on the Clyde in Scotland, in which all the shells, with the exception of fifteen in a hundred, are of living northern species. In both these cases, the assemblage of fossils exhibits a corresponding amount of divergence from the existing state of things. The advantage of the test here pointed out consists in supplying us with a common point of departure in all countries however remote; and when we find, that in North America there are tertiary strata in which, like those of Paris and London, more than 95 per cent. of the fossil shells differ from any now living, we may presume that these may be of nearly the same relative antiquity.

It must, however, be admitted, that the farther we recede from the present times, and the smaller the relative number of recent as compared with extinct species in the tertiary deposits, the less confidence can we place in the exact value of this test, especially when comparing the strata of

remote regions; for we cannot presume that the rate of former alterations in the animate world, or the continual going out and coming in of species, has been every where equal in equal quantities of time. The form of the land and sea, and the climate, may have changed more in one region than in another; and consequently there may have been a greater destruction and renovation of species in one part of the globe than elsewhere. But although these considerations should put us on our guard against relying too implicitly on the accuracy of this test, yet it can never fail to throw great light on the chronological relations of tertiary groups with each other, and the connection of their fossils with the existing state of the organic world.

Many authors have divided the European tertiary strata into three groups — lower, middle, and upper; the lower comprising the oldest formations of Paris and London before-mentioned; the middle those of Bordeaux and Touraine; and the upper all those newer than the middle group.

When engaged in 1828 in preparing my work on the Principles of Geology, I conceived the idea of classing the whole series of tertiary strata in four groups, and endeavouring to find characters for each, expressive of their different degrees of affinity to the living fauna. With this view, I obtained information respecting the specific iden-

tity of many tertiary and recent shells from several Italian naturalists, and among others from Professors Bonelli, Guidotti, and Costa. Having in 1829 become acquainted with M. Deshayes, of Paris, already well known by his conchological works, I learnt from him that he had arrived, by independent researches, and by the study of a large collection of fossil and recent shells, at very similar views respecting the arrangement of tertiary formations. At my request he drew up, in a tabular form, lists of all the shells known to him to occur both in some tertiary formation and in a living state, for the express purpose of ascertaining the proportional number of fossil species identical with the recent which characterized successive groups; and this table was published by me in 1833.* The number of tertiary fossil shells examined by M. Deshayes was about 3000; and the recent species with which they had been compared, about 5000. The result then arrived at was, that in the lower tertiary strata, or those of London and Paris, there were about 3½ per cent. of species identical with recent; in the middle tertiary of the Loire and Gironde about 17 per cent.; and in the upper tertiary or Subapennine beds, from 35 to 50 per cent. In formations still more modern, some of which I had

* See Princ. of Geol. vol. iii., 1st ed.

particularly studied in Sicily, where they attain a vast thickness and elevation above the sea, the number of species identical with those now living was believed to be from 90 to 95 per cent. For the sake of clearness and brevity, I proposed to give short technical names to these four groups, or the periods to which they respectively belonged. I called the first or oldest of them Eocene, the second Miocene, the third Older Pliocene, and the last or fourth Newer Pliocene. The first of the above terms, Eocene, is derived from ηως, eos, *dawn*, and καινος, cainos, *recent*, because the fossil shells of this period contain an extremely small proportion of living species, which may be looked upon as indicating the dawn of the existing state of the testaceous fauna, no recent species having been detected in the older or secondary rocks.

The term Miocene (from μειον, meion, *less*, and καινος, cainos, *recent*,) is intended to express a minor proportion of recent species, the term Pliocene (from πλειον, pleion, *more*, and καινος, cainos, *recent*,) a comparative plurality of the same. It may assist the memory of students to remind them, that the *Mi*ocene contain a *mi*nor proportion, and *Pl*iocene a comparative *pl*urality of recent species; and that the greater number of recent species always implies the more modern origin of the strata.

The distribution of the fossil species from which

the results before mentioned were obtained in 1830 by M. Deshayes was as follows: —

In the formations of the Pliocene periods, older and newer - - - - - -	777
In the Miocene - - - - -	1021
In the Eocene - - - - -	1238
	3036

Since the year 1830 the progress of conchological science has been most rapid, and the number of living species obtained from different parts of the globe has been raised from about 5000 to more than 10,000. New fossil species have also been added to our collections in great abundance; and at the same time a more copious supply of individuals both of fossil and recent species, some of which were previously very rare, have been procured, affording more ample data for determining the specific character. Besides the reforms introduced in consequence of these new zoological facilities, other errors of a geological nature have been in many instances removed. Thus, for example, the fossils of more than one member of the tertiary series occurring in the same district, had occasionally been confounded together, as in the case of the Crag of Norfolk and Suffolk, afterwards to be mentioned*; and these being now separated, the shells belonging respectively to each division

* See chap. XIV.

exhibit a very different relation to the existing fauna from the mean result previously obtained.

Many years must be devoted to the study of the European tertiary formations before a complete revision can be effected in their chronological arrangement, due regard being paid to the proportional number of recent species contained in each. It need scarcely be remarked, that numerical estimates such as those now alluded to, must be more vague in regions where we are imperfectly acquainted with the shells of the neighbouring sea, as in the case of the Mediterranean, than where we are much farther advanced in our knowledge, as with respect to the testaceous fauna of the British Isles. The comparison, therefore, of the fossils of several of our English tertiary formations with the known recent shells is highly interesting, and the contrast which is afforded by the results is sufficiently striking, as the following table will show.

Periods.	Localities, &c.	Percentage of recent.	Number of Fossils compared.
Post-Pliocene	Freshwater of valley of the Thames	99 to 100	40
Newer Pliocene	Marine strata near Glasgow	85 to 90	160
Older Pliocene	Norwich Crag	60 to 70	111
Miocene	Suffolk, red and coralline Crag	20 to 30	450
Eocene	London and Hampshire	1 or 2	400

The deposits enumerated in the above list will be treated of in the sequel, and I shall point out some of the continental groups which may agree in age with those of England, and others which may probably require to be intercalated as referable to periods intermediate in date between those of which we happen to possess monuments in our own country.

It has long been a received opinion, that the more ancient the tertiary strata, the more nearly do the fossil testacea approach in their generic forms, and in the number of species, to the shells of warmer and tropical seas; so that in central and southern Europe, the climate of the Eocene period appears to have been nearly tropical, that of the Miocene sub-tropical, an opinion which is not only borne out by the shells, but, to a certain extent, by the corals, reptiles, and fish. The climate of the Pliocene formations resembled more nearly that now prevailing in corresponding latitudes;—but in some of the newer Pliocene and Post-Pliocene strata of the north of Europe and Canada, there are indications, as before observed *, of a fauna more arctic than that now inhabiting the same regions.

* See p. 236.

CHAPTER XIII.

NEWER AND OLDER PLIOCENE FORMATIONS.

Freshwater deposits in valley of Thames — Comparative longevity of species in the mammalia and testacea — Strata near Glasgow — Madeira — Newer Pliocene formations largely developed in Sicily — Limestone of great thickness and elevation — Alternation of marine and volcanic formations — Proofs of slow accumulation — Great geographical changes in Sicily since the living fauna and flora began to exist — Older Pliocene strata — Norwich Crag — Subapennine beds — Asti, Sienna, Rome — Osseous breccias and cavern deposits — Sicily — Kirkdale — Origin of stalactite — Australian cave-breccias — Teeth of fossil quadrupeds.

At several points in the valley of the Thames, as at Brentford, Ilford, Grays, and Erith, a freshwater deposit occurs, consisting of horizontal strata of loam, sand, and gravel, from 20 to 60 feet thick. More than 40 species of terrestrial and freshwater shells derived from these and similar deposits on the banks of the Stour and Medway, appear to be identical with species now living in Britain, with the exception of three, namely, *Paludina marginata* (Fig. 102.), *Unio littoralis* (Fig. 29.), now living in the Loire, and *Cyrena trigonula* (Fig. 26.). The fossil last-mentioned is abundant, and deserves notice, because the genus

Cyrena is no longer European. Some conchologists, however, regard the species as identical with the Egyptian shell, *C. consobrina*, now living in the Nile.

Bones both of herbivorous and carnivorous mammalia are also contained in these freshwater strata. The elephant, or mammoth, is particularly abundant, as are the ox, deer, and horse. An extinct species of rhinoceros (see Fig. 122.), and hippopotamus have been also found, and still more rarely the bear, hyæna, and tiger. *

The student has here a good exemplification of the manner in which the fossils of the more modern formations, when traced back retrospectively, first begin to diverge from the recent type. A small intermixture of exotic species is recognized, and some doubts are entertained by the naturalist respecting the perfect identity of one or two fossil with recent species. At the same time the mammalia are in part extinct, and partly identical with those now inhabiting the country.

The phenomenon last mentioned and which was before alluded to (p. 214.), is by no means confined to Europe, for Mr. Darwin found at Bahia Blanca, in South America, lat. 39° S. near the northern confines of Patagonia, fossil remains of the extinct mammiferous genera Megatherium, Mega-

* Morris, Mag. of Nat. Hist. 1838, p. 539.

lonyx, Toxodon, and others, associated with marine shells, almost all of species already ascertained to be still living in the contiguous sea.*

It was before hinted (p. 214.), that the longevity of species in the testacea appears by geological evidence to have exceeded that of the mammalia, the latter being probably endowed with less capacity for enduring those changes of climate and other external circumstances which take place in the course of ages on the earth's surface.

The above remarks will show that the freshwater formations of the basin of the Thames, if not referable to the Post-Pliocene period, belong to the close of the era immediately antecedent, and they afford a good illustration of the shades by which the newer Pliocene formations pass insensibly into others more modern, which in their turn blend as we have seen with those of the human or historical times.

I have already alluded to certain marine strata overlying till near Glasgow, and at other points on the Clyde, in which the shells are for the most part British, with an intermixture of some arctic species, and others, about a tenth or more of the whole, supposed to be extinct. (See p. 257.) This formation may also be called Newer Pliocene.

Madeira. — The soil and subsoil of the island

* Zool. of Beagle, part 1. pp. 9. 111.

of Madeira, affords a good exemplification of a fossil fauna, making a slight departure from that now existing on the same spot, as it is filled for a great depth with land shells, one sixth of which are of extinct species, the others still living on the island. At one point a mass of pumice or volcanic tuff has been showered down on this deposit, or has been washed over it by a land flood.*

Sicily. — In no part of Europe are the newer Pliocene formations seen to enter so largely into the structure of the earth's crust, or to rise to such heights above the level of the sea, as in Sicily. They cover nearly half the island, and near its centre, at Castrogiovanni, they reach an elevation of 3000 feet. They consist principally of two divisions, the upper calcareous, the lower argillaceous, both of which may be seen at Syracuse, Girgenti, and Castrogiovanni.

A great variety of shells have been found at Palermo in this formation, and it has been remarked by Dr. Philippi, to whom we are indebted for the best work on the tertiary fossils of this island, that about one fifth of the species differ from those now known to exist in the Mediterranean, whereas the strata in Ischia, before alluded to, and others at the base of Etna and at Cape

* J. Smith, Esq. Proceedings Geol. Soc. No. 73.

Melazzo are more modern, the fossils agreeing entirely with the present Mediterranean fauna. As the shells from all these Sicilian beds, whether Post-Pliocene or older, have generally been confounded together, I have no doubt that the proportion of 95 per cent. of recent species, given me by M. Deshayes, in 1828, is higher than he would have deduced from the fossils of the Pliocene beds of Sicily considered separately.

I have lately examined with scrupulous care, and with the assistance of Mr. G. Sowerby, 303 species brought from these newer Pliocene beds, and we found that 73 of them could not be identified with any living species from the Mediterranean, which gives a proportion of more than a fifth unknown. But, on the other hand, it should be remarked, that only 536 recent Mediterranean shells were known to Philippi, and Mr. Sowerby was only able to refer to 550 in the cabinets in London, a number which we may fairly presume to be part only of the existing fauna of the Mediterranean. For we may safely assume from the geographical position of this sea, the temperature of its waters, and the richness of its littoral fauna, that it is inhabited by a greater number of testacea than the British seas, which have already yielded 600 species. The proportion, therefore, of extinct or unknown fossils may hereafter be reduced to 10 or 15 per cent., in

which list we may expect to find those species, such as *Buccinum prismaticum*, *B. semistriatum*, *Pleurotoma rotata*, *Fusus crispus*, and *Mitra plicatula* (See Pl. 1. Figs. 7, 8, 9. 11, and 12.), which are common to Sicily and the older Subapennine beds of Italy.

If, then, we feel at liberty to assume that between 80 and 90 per cent. of the Sicilian fossil shells are of species still living, this conclusion will naturally seem astonishing to all who are accustomed in the north of Europe to see the more modern deposits attaining an insignificant thickness, and almost always soft and incoherent in texture.

The newer Pliocene rocks of Sicily rest immediately and in conformable stratification on secondary marls and clays, some of which are celebrated for containing gypsum, salt, and sulphur in abundance. These last have been shown by Hoffmann to agree nearly in age with the English chalk.*

The upper or calcareous member of the newer Pliocene group before mentioned consists, in some places, of a yellowish-white stone, like the calcaire grossier of Paris, in others, of a rock nearly

* See the posthumous work of Hoffmann, whose excellent account of the geology of Sicily is accompanied by a map, which has enabled me to correct and improve that of the eastern half of the island, formerly given in the Principles of Geology, and now republished, (see Pl. 2.)

as compact as marble. Its aggregate thickness amounts sometimes to 700 or 800 feet. It usually occurs in regular horizontal beds, and is occasionally intersected by deep valleys, such as those of Sortino and Pentalica, in which are numerous caverns. The fossils are in every stage of preservation, from shells retaining portions of their animal matter and colour, to others which are mere casts.

The limestone passes downwards into a sandstone and conglomerate, below which is clay and blue marl, like that of the Subapennine hills, from which perfect shells and corals may be disengaged. The clay sometimes alternates with yellow sand.

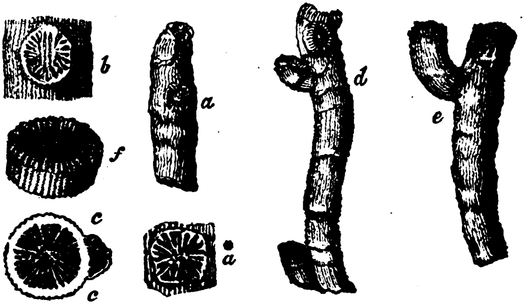
In the annexed map it will be seen, that south of the plain of Catania is a region in which the tertiary beds are intermixed with volcanic matter, which has been for the most part the product of submarine eruptions. It appears that, while the clay, sand, and yellow limestone before-mentioned, were in course of deposition at the bottom of the sea, volcanos burst out beneath the waters, like that of Graham island, in 1831, and these explosions recurred again and again at distant intervals of time. Volcanic ashes and sand were showered down and spread by the waves and currents so as to form strata of tuff, which are found intercalated between beds of limestone and clay containing

marine shells, the thickness of the whole mass exceeding 2000 feet. The fissures through which the lava rose may be seen in many places forming what are called *dikes*, which will be described in the next volume.

In part of the region above alluded to, as, for example, near Lentini, a conglomerate occurs in which I observed many pebbles of volcanic rocks covered by full grown *serpulæ*. We may explain the origin of these by supposing that there were some small volcanic islands which may have been destroyed from time to time by the waves, as Graham Island has been swept away since 1831. The rounded blocks and pebbles of solid volcanic matter, after being rolled for a time on the beach of such temporary islands, were carried at length into some tranquil part of the sea, where they lay for years, while the marine *serpulæ* adhered to them, their shells growing and covering their surface, as they are seen adhering to the shell figured in p. 48. Finally, the bed of pebbles was itself covered with strata of shelly limestone. At Vizzini, a town not many miles distant to the S. W. (see Map), I remarked another striking proof of the gradual manner in which these modern rocks were formed, and the long intervals of time which elapsed between the pouring out of distinct sheets of lava. A bed of oysters no less than twenty feet in thickness rests upon a current

of basaltic lava. The oysters are perfectly identifiable with our common eatable species. Upon the oyster bed, again, is superimposed a second mass of lava, together with tuff or peperino. In the midst of the same alternating igneous and aqueous formations is seen near Galieri, not far from Vizzini, a horizontal bed, about a foot and a half in thickness, composed entirely of a common Mediterranean coral (*Caryophyllia cespitosa*, Lam.). These corals stand erect as they grew; and, after being traced for hundreds of yards, are again found at a corresponding height on the opposite side of the valley.

Fig. 111.



Caryophyllia cespitosa, Lam. (*Cladocora cespitosa*, Ehr.)

a. Stem with young stem growing from its side.
*a**. Young stem of same twice magnified.
b. Portion of branch, twice magnified, with the base of a lateral branch; the exterior ridges of the main branch appearing through the lamellæ of the lateral one.
c. Transverse section of same, proving, by the integrity of the

main branch, that the lateral one did not originate in a subdivision of the animal.

d. A branch, having at its base another laterally united to it, and two young corals at its upper part.

e. A main branch, with a full grown lateral one.

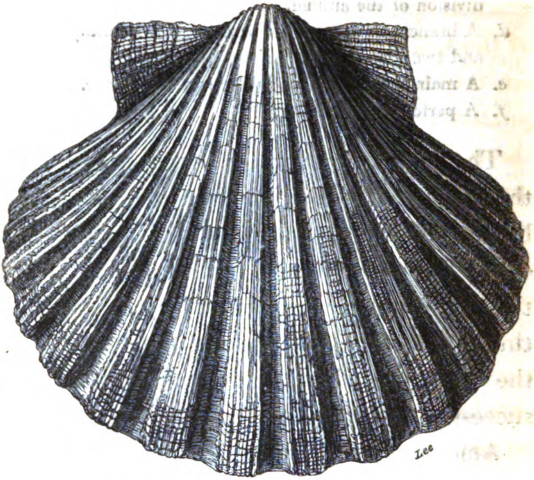
f. A perfect terminal star.

The corals are usually branched, but not by the division of the animal as some have supposed, but by the attachment of young individuals to the sides of the older ones, and we must understand this mode of increase, in order to appreciate the time which was required for the building up of the whole bed of coral during the growth of many successive generations.*

Among other fossil shells met with in these Sicilian strata, and which still continue to abound in the Mediterranean, I may mention *Turbo rugosus*, *Tornatella fasciata*, and other species figured in Pl. 1. (See Figs. 1. 3, 4, 5, 6, 7. 13 and 14.); but no shell is more conspicuous, from its size and frequent occurrence, than the great scallop, *Pecten Jacobæus* (see Fig. 112.), now so common in the neighbouring seas. We see this shell in the calcareous beds at Palermo in great numbers, in the limestone at Girgenti, and in that which alternates with volcanic rocks in the country between Syracuse and Vizzini, often at great heights above the sea.

* I am indebted to Mr. Lonsdale for the details above given respecting the structure of this coral.

Fig. 112.



Pecten jacobæus; half natural size.

The more we reflect on the preponderating number of these recent shells, the more we are surprised at the great thickness, solidity, and elevation of the rocky masses in which they are entombed, and the vast amount of geographical change which has taken place since their origin. It must be remembered that, before they began to rise above the waters, the uppermost strata of the whole must have been thrown down. In order, therefore, to form a just conception of their antiquity, we must first examine singly the innumerable minute parts of which the whole is made up, the successive beds of shells, corals, volcanic ashes, conglomerates, and sheets of lava; and we must

afterwards contemplate the time required for the gradual upheaval of the rocks, and the excavation of the valleys. As yet, the historical period seems scarcely to form an appreciable unit in the computation, for we find ancient Greek temples, like those of Girgenti (Agrigentum), built of the modern limestone of which we are speaking, and resting on a hill composed of the same; the site having remained to all appearance unaltered since the Greeks first colonized the island.

The modern geological date of the rocks in this region leads to another singular and unexpected conclusion, namely, that the fauna and flora of a large part of Sicily, are of higher antiquity than the country itself, having not only flourished before the lands were raised from the deep; but even before their materials were brought together beneath the waters. The chain of reasoning which conducts us to this opinion may be stated in a few words. The larger part of the island has been converted from sea into land since the Mediterranean was peopled with nearly all the living species of testacea and zoophytes. We may therefore presume that, before this region emerged, the same land and river shells, and almost all the same animals and plants, were in existence which now people Sicily; for the terrestrial fauna and flora of this island are precisely the same as that of other lands surrounding the Mediterranean.

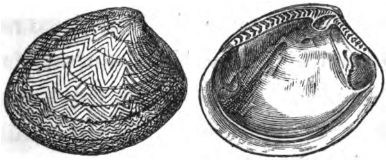
There appear to be no peculiar or indigenous species, and those which are now established there must be supposed to have migrated from pre-existing lands, just as the plants and animals of the Neapolitan territory have colonized Monte Nuovo, since that volcanic cone was thrown up in the sixteenth century.

Such conclusions throw a new light on the adaptation of the attributes and migratory habits of animals and plants to the changes which are unceasingly in progress in the physical geography of the globe. It is clear that the duration of species is so great, that they are destined to outlive many important revolutions in the configuration of the earth's surface; and hence those innumerable contrivances for enabling the subjects of the animal and vegetable creation to extend their range; the inhabitants of the land being often carried across the ocean, and the aquatic tribes over great continental spaces. It is obviously expedient that the terrestrial and fluviatile species should not only be fitted for the rivers, valleys, plains, and mountains which exist at the era of their creation, but for others that are destined to be formed before the species shall become extinct; and, in like manner, the marine species are not only made for the deep and shallow regions of the ocean existing at the time when they are called into being, but for tracts that may be submerged

or variously altered in depth during the time that is allotted for their continuance on the globe.

Older Pliocene strata—Norwich Crag.—We must now endeavour to carry our retrospect one step farther, and treat of the era immediately antecedent to that last considered. Recent investigations have shown that the deposits provincially termed Crag in Norfolk and Suffolk, all of which were formerly confounded together, and referred to one period, may be subdivided into two very distinct groups. The oldest of these, comprising the Red and Coralline crag of Suffolk, will be described in the next chapter; the newest is that well seen in the neighbourhood of Norwich, as also at Southwold, in Suffolk. The shelly beds of sand and loam, sometimes forty feet thick, which there rest upon the chalk, were evidently accumulated where one or more rivers entered the sea. In this fluvio-marine formation, about twenty species of land and freshwater shells, and about ninety marine species, have been obtained. As in this number the proportion now known as living does not exceed the

Fig. 113.



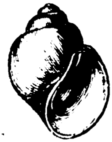
Nucula Cobboldiæ.

Fig. 114.

Tellina obliqua.

ratio of 60 per cent, the strata may be classed as Older Pliocene. Among the more common of the extinct testacea of these beds are *Nucula Cobboldiæ* (Fig. 113.) and *Tellina obliqua* (Fig. 114.)

Fig. 115.



Natica helicoides, Johnston.

Natica helicoides (Fig. 115.) is an example of a species, formerly known only as fossil, but which has recently been found living in our seas.* The echinodermata and fish of this deposit have none of them been hitherto identified with living species; but this may in some degree be owing to the comparatively small progress made as yet in our knowledge of these departments of the British submarine fauna.

Bones of mammalia are frequently met with, and among them is the *Mastodon longirostris* (Fig. 121.), as determined by Mr. Owen from a specimen of the upper jaw found by J. B. Wigham, Esq. in 1838, at Postwick, near Norwich. In the same formation occur bones of the elephant, horse, pig, deer, and the jaws and teeth of field mice. (Fig. 132.) The femur of a seal, apparently distinct from any British species, has also been recognized by Mr. Owen.

Strata containing the same shells as those near Norwich have been found by Mr. Bean, at Bridlington, in Yorkshire.

* See Phil. Mag. No. 104., May 1840., p. 365.

Subapennine strata. — The Apennines, it is well known, are composed chiefly of secondary rocks, forming a chain which branches off from the Ligurian Alps and passes down the middle of the Italian peninsula. At the foot of these mountains, on the side both of the Adriatic and the Mediterranean, are found a series of tertiary strata, which form, for the most part, a line of low hills occupying the space between the older chain and the sea. Brocchi, as we have seen (p. 273.), was the first Italian geologist who described this newer group in detail, giving it the name of the Subapennines; and he classed all the tertiary strata of Italy, from Piedmont to Calabria, as parts of the same system. Certain mineral characters, he observed, were common to the whole; for the strata consist generally of light brown or blue marl, covered by yellow calcareous sand and gravel. There are also, he added, some species of fossil shells which are found in these deposits throughout the whole of Italy.

We have now, however, satisfactory evidence that the Subapennine beds of Brocchi belong, at least, to three periods. To the Miocene we can refer a portion of the strata of Piedmont, those of the hill of the Superga, for example, and those of freshwater origin in the Upper Val d'Arno; to the Older Pliocene part of the strata of northern Italy, of Tuscany, and of Rome; while the tufa-

ceous formations of Naples, of Ischia, and the calcareous strata of Otranto, are referable to the Newer Pliocene, and in great part to the Post-Pliocene period.

That there is a considerable correspondence in the mineral composition of these different Italian groups is undeniable; but not that exact resemblance which should lead us to assume a precise identity of age, unless the fossil remains agreed very closely. It is now indispensable that a new scrutiny should be made in each particular district, of the fossils derived from the upper and lower beds—especially such localities as Asti and Parma, where the formation attains a great thickness. From these places I possess about 200 species of shells, procured indiscriminately from the higher and inferior strata, and find the recent species to be in the proportion of at least one third. At Sienna the shells of the incumbent yellow sand are generally believed to approach much more nearly, as a whole, to the recent fauna of the Mediterranean than those in the subjacent blue marl.

The greyish brown or blue marl of the Subapennine formation is very aluminous, and usually contains much calcareous matter and scales of mica. Near Parma it attains a thickness of 2000 feet, and is charged throughout with marine shells, some of which lived in deep, others in

shallow water, while a few belong to fresh water genera, and must have been washed in by rivers. Among these last I have seen the common *Limnea palustris* in the blue marl, filled with small marine shells. The wood and leaves, which occasionally form beds of lignite in the same deposit, may have been carried into the sea by similar causes. The shells, in general, are soft when first taken from the marl, but they become hard when dried. The superficial enamel is often well preserved, and many shells retain their pearly lustre, part of their external colour, and even the ligament which unites the valves. No shells are more usually perfect than the microscopic foraminifera, which abound near Sienna, where more than a thousand full-grown individuals may be sometimes poured out of the interior of a single univalve of moderate dimensions.

The other member of the Subapennine group, the yellow sand and conglomerate, constitutes, in most places, a border formation near the junction of the tertiary and secondary rocks. In some cases, as near the town of Sienna, we see sand and calcareous gravel resting immediately on the Apennine limestone, without the intervention of any blue marl. Alternations are there seen of beds containing fluviatile shells, with others filled exclusively with marine species; and I observed oysters attached to many

limestone pebbles. This appears to have been a point where a river, flowing from the Apennines, entered the sea when the tertiary strata were formed.

The sand passes in some districts into a calcareous sandstone, as at San Vignone. Its general superposition to the marl, even in parts of Italy and Sicily where the date of its origin is very distinct, may be explained if we consider that it may represent the deltas of rivers and torrents, which gained upon the bed of the sea where blue marl had previously been deposited. The latter, being composed of the finer and more transportable mud, would be conveyed to a distance, and first occupy the bottom, over which sand and pebbles would afterwards be spread, in proportion as rivers pushed their deltas farther outwards. In some large tracts of yellow sand it is impossible to detect a single fossil, while in other places they occur in profusion. Occasionally the shells are silicified, as at San Vitale, near Parma, from whence I saw two individuals of recent species, one freshwater and the other marine (*Limnea palustris*, and *Cytherea concentrica*, Lam.), both perfectly converted into flint.*

Rome.—The seven hills of Rome are composed

* For figures of some of the common Subapennine shells, see Pl. 1.

partly of marine tertiary strata, as those of Monte Mario, for example, of the Older Pliocene period, and partly of superimposed volcanic tuff, on the top of which are usually cappings of a fluviatile and lacustrine deposit. Thus, on Mount Aventine, the Vatican, and the Capitol, we find beds of calcareous tufa with incrusted reeds, and recent terrestrial shells, at the height of about 200 feet above the alluvial plain of the Tiber. The tusk of the mammoth has been procured from this formation, but the shells appear to be all of living species, and must have been imbedded when the summit of the Capitol was a marsh, and constituted one of the lowest hollows of the country as it then existed. It is not without interest that we thus discover the extremely recent date of a geological event which preceded an historical era so remote as the building of Rome.

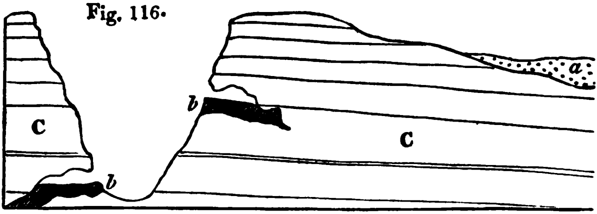
OSSEOUS BRECCIAS AND DEPOSITS IN CAVES OF THE PLIOCENE PERIOD.

Sicily.—Caverns filled with marine breccias, at the base of ancient sea cliffs, have been already mentioned in the sixth chapter; and it was noticed, respecting the cave of San Ciro, near Palermo, that above a bed of sand filled with sea-shells, almost all of recent species, was a breccia, composed of fragments of calcareous rock, and

the bones of animals. (P. 152.) In the sand at the bottom of that cave, Dr. Philippi found about forty-five marine shells, all clearly identical with recent species, except two or three. The bones in the incumbent breccia are chiefly those of the mammoth (*E. primigenius*), with some belonging to an hippopotamus, distinct from the recent species, and smaller than that usually found fossil. (See Fig. 123.) Several species of deer, also, and, according to some accounts, the remains of a bear, were discovered. These mammalia are probably referable to the Post-Pliocene period.

That the tertiary limestone of the south of Sicily is sometimes full of caverns has been already mentioned; and the student will at once perceive, that all the quadrupeds of which the remains are found in the stalactite of these caverns, being of later origin than the rocks, must be re-

Fig. 116.



a. Alluvium, } containing the remains of quadrupeds
b, b. Deposits in caves, } for the most part extinct.

C. Limestone, containing the remains of shells of which above 80 per cent. are recent.

ferable to the close of the tertiary epoch, if not of still later date. The situation of one of these caves, in the valley of Sortino, is represented in the annexed section.

England.—In a cave at Kirkdale, about twenty-five miles N. N. E. of York, the remains of about 300 hyænas, belonging to individuals of every age, have been detected; and Dr. Buckland, after carefully examining the spot, has shown that the hyænas lived there; a fact attested by the quantity of their dung, which, as is the case of the living hyæna, is of nearly the same composition as bone, and almost as durable. In the cave were found the remains of the ox, young elephant, hippopotamus, rhinoceros, horse, bear, wolf, hare, water-rat, and several birds. All the bones have the appearance of having been broken and gnawed by the teeth of the hyænas; and they occur confusedly mixed in loam or mud, or dispersed through a crust of stalagmite which covers it. In these and many other cases it is supposed that portions of herbivorous quadrupeds have been dragged into caverns by beasts of prey, and have served as their food, an opinion quite consistent with the known habits of the living hyæna.

Other examples occur of fissures into which animals have fallen from time to time, or have been washed in from above, together with al-

luvial matter and fragments of rock detached by frost, forming a mass which may be united into a bony breccia by stalagmitic infiltrations. Frequently we discover a long suite of caverns connected by narrow and irregular galleries, which hold a tortuous course through the interior of mountains, and seem to have served as the subterranean channels of springs and engulphed rivers. Many streams in the Morea are now carrying bones, pebbles, and mud into underground passages of this kind.* If, at some future period, the form of this country should be wholly altered by subterranean movements and new valleys shaped out by denudation, many portions of the former channels of these engulphed streams may communicate with the surface, and become the dens of wild beasts, or the recesses to which quadrupeds retreat to die. Certain caves of France, Germany, and Belgium, may have passed successively through these different conditions, and in their last state may have remained open to the day for several tertiary periods. It is nevertheless remarkable, that in Europe the fossil remains of mammalia belong almost exclusively to those of the Pliocene or Post-Pliocene periods, and not to the Miocene or Eocene epochs, and when

* See Principles of Geology.

they are accompanied by land or river shells, these agree in great part, or entirely, with recent species.

As the preservation of the fossil bones is due to a slow and constant supply of stalactite, brought into the caverns by water dropping from the roof, the source and origin of this deposit has been a subject of curious inquiry. The following explanation of the phenomenon has been recently suggested by the eminent chemist Liebig. On the surface of Franconia, where the limestone abounds in caverns, is a fertile soil, in which vegetable matter is continually decaying. This mould or humus, being acted on by moisture and air, evolves carbonic acid which is dissolved by rain. The rain water, thus impregnated, permeates the porous limestone, dissolves a portion of it, and afterwards, when the excess of carbonic acid evaporates in the caverns, parts with the calcareous matter, and forms stalactite.

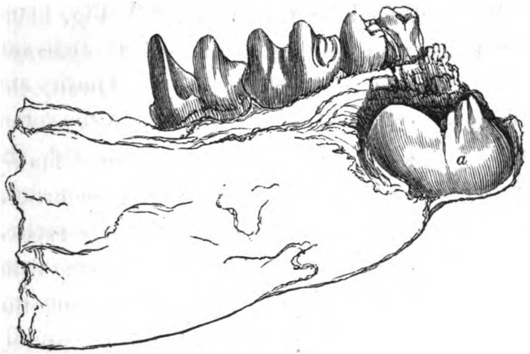
Australian cave-breccias. — Ossiferous breccias are not confined to Europe, but occur in all parts of the globe; and those lately discovered in fissures and caverns in Australia correspond closely in character with what has been called the bony breccia of the Mediterranean, in which the fragments of bone and rock are firmly bound together by a red ochreous cement.

Some of these caves have been examined by Sir T. Mitchell, in the Wellington Valley, about 210 miles west of Sydney, on the river Bell, one of the principal sources of the Macquarie, and on the Macquarie itself. The caverns often branch off in different directions through the rock, widening and contracting their dimensions, and the roofs and floors are covered with stalactite. The bones are often broken, but do not seem to be water-worn. In some places they lie imbedded in loose earth, but they are usually included in a breccia.

The remains found most abundantly are those of the kangaroo, of which there are four species, besides which the genera *Hypsiprymnus*, *Phalangista*, *Phascolomys*, and *Dasyurus*, occur. There are also bones, formerly conjectured by some osteologists to belong to the hippopotamus, and by others to the dugong, but which are now referred by Mr. Owen to a marsupial genus, allied to the *Wombat*.

In the fossils above enumerated, several species are larger than the largest living ones of the same genera now known in Australia. The annexed figure of the right side of a lower jaw of a kangaroo (*Macropus atlas*, Owen) will at once be seen to exceed in magnitude the corresponding part of the largest living kan-

Fig. 117.

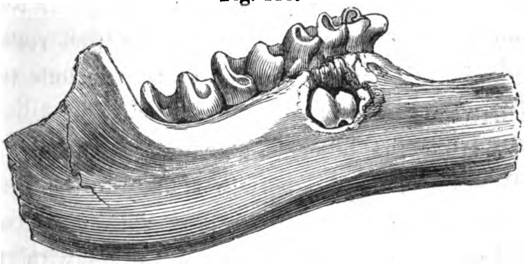


Macropus atlas, Owen.

a, permanent false molar, in the alveolus.

garoo, which is represented in Fig. 118. In both these specimens part of the substance of the jaw

Fig. 118.



Lower jaw of largest living species of kangaroo (*Macropus major*).

has been broken open, so as to show the permanent false molar (*a*, Fig. 117.) concealed in the socket. From the fact of this molar not having

been cut, we learn that the individual was young, and had not shed its first teeth. In Fig. 119. a front tooth of the same species of Kangaroo is represented. The discovery of Mr. Owen, that all these extinct quadrupeds of Australia belong to the marsupial family, or, in other words, that they are referable to the same peculiar type of organization which now distinguishes the Australian mammalia from other parts of the globe, is full of interest, because we find, in like manner, that in those regions of South America to which the families of the Armadillo, Llama, and Capybara, are now confined, there are extinct species of the same families in a fossil state, facts which point to a general law of relationship between the recent mammiferous fauna and that of the periods immediately antecedent.

Fig. 119.

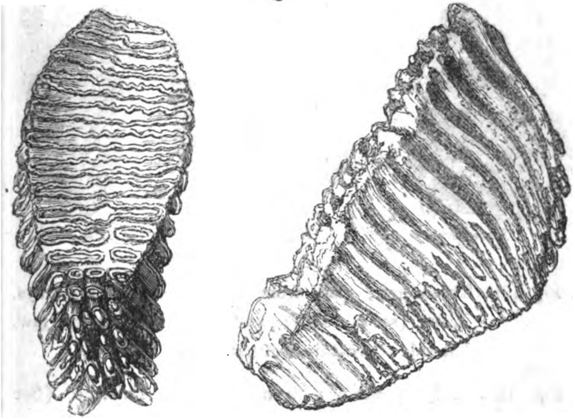
Incisor of *Macropus*.

Whether the breccias, above alluded to, of the Wellington Valley, appertain strictly to the Pliocene period cannot be affirmed with certainty, until we are more thoroughly acquainted with the recent quadrupeds of the same district, and until we learn what species of fossil land shells, if any, are buried in the deposits of the same caves.

To those who have never studied comparative anatomy it may seem scarcely credible, that a

single bone taken from any part of the skeleton may enable a skilful osteologist to distinguish, in many cases the genus, and sometimes the species, of quadruped to which it belonged. Although few geologists can aspire to such knowledge, which must be the result of long practice and study, they will nevertheless derive great advantage from learning what is comparatively an easy task, to distinguish the principal divisions of the mammalia by the forms and characters of their teeth. The annexed figures, all taken from original specimens, may be useful in assisting the student to recognize the teeth of many genera most frequently found fossil in Europe:—

Fig. 120.



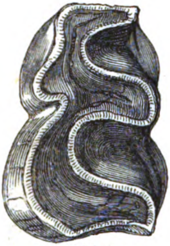
Elephas primigenius (or Mammoth); molar of upper jaw, right side; one third of nat. size.

a. grinding surface. *b.* side view.

Fig. 121.

Mastodon longirostris (Norwich Crag, Postwick); second true molar, left side, upper jaw; grinding surface, nat. size. (See p. 300.)

Fig. 122.



Rhinoceros.

Fig. 123.

Hippopotamus.

Fig. 124.

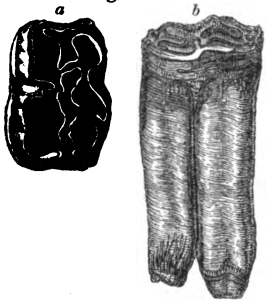
Pig.

Fig. 122. Rhinoceros; fossil from fresh-water beds of Grays, Essex (see p. 287.); penultimate molar, lower jaw, left side; two-thirds of nat. size.

Fig. 123. Hippopotamus; from cave near Palermo (See p. 306.); molar tooth; two thirds of nat. size.

Fig. 124. *Sus scrofa*, Lin. (common pig); from shell-marl, Forfarshire; posterior molar, lower jaw; nat. size.

Fig. 125.



Horse.

Fig. 126.

Tapir.

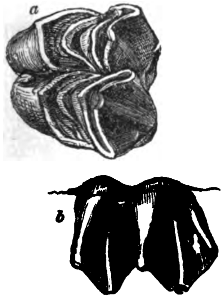
Fig. 125. *Equus caballus*, Lin. (common horse); from the shell-marl, Forfarshire; second molar, lower jaw.

a. grinding surface, two thirds nat. size.

b. side view of same, half nat. size.

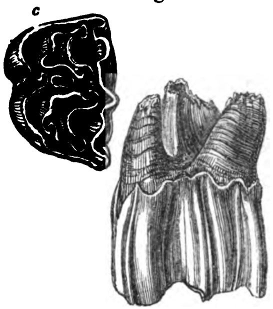
Fig. 126. *Tapirus Americanus;* recent; third molar, upper jaw; nat. size.

Fig. 127.



a. b. Deer.

Fig. 128.



c. d. Ox.

Fig. 127. Elk (*Cervus alces*, Lin.); recent; molar of upper jaw.

a. grinding surface. *b.* side view; two thirds of nat. size.

Fig. 128. Ox, common, from shell-marl, Forfarshire; true molar upper jaw; two thirds nat. size.

c. grinding surface. *d.* side view.

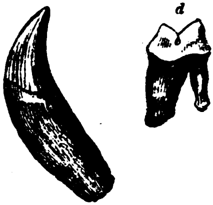
Fig. 129.

a b

Bear.

Fig. 130.

c d



Tiger.

Fig. 129. *a.* incisor of bear (*Ursus spelæus*); from cave near Liege.
b. molar of left side, upper jaw; one third of nat. size.

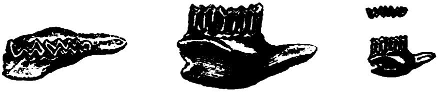
Fig. 130. *c.* incisor of tiger (*Felis tigris*); recent.
d. outside view of posterior molar, lower jaw; one-third of nat. size.

Fig. 131.

Hyæna; second molar, left side, lower jaw; nat. size. Cave of Kirkdale (see p. 307.)

Fig. 132.

a b c



Teeth of a new species of *Arvicola* (field-mouse); from the Norwich Crag. (See p. 300.)

a. grinding surface. *b.* side view of same.
c. nat. size of *a* and *b*.

CHAPTER XIV.

MIOCENE FORMATIONS.

Strata of Suffolk termed crag — Distinction of red and coralline crag — Fossils, and proportion of recent species — Inferences as to climate — Faluns of Touraine — Shells and corals — Comparison of the Faluns and the Suffolk crag — Whether contemporaneous — Miocene strata of Bordeaux, Switzerland, Lisbon, Styria, Mayence, and the Val d'Arno.

THE Miocene formations, corresponding for the most part with those named "middle tertiary," will next claim our attention. Among the strata referred to this division in the 12th chapter, those of Touraine in France, and Suffolk in England, were particularly mentioned; for, although there is a considerable difference in the fossils of these two groups, there is strong ground for suspecting that they were nearly contemporaneous.

The tertiary strata of Suffolk, to which the provincial name of "crag" has been given, are confined chiefly to the eastern part of that county, and may be divided into two masses, the upper of which has been termed the Red, and

the lower the Coralline Crag.* The upper deposit consists chiefly of quartzose sand, with occasional intermixture of shells, for the most part rolled, and sometimes comminuted. The lower or Coralline crag is of very limited extent, ranging over an area about twenty miles in length, and three or four in breadth, between the rivers Alde and Stour. It is generally calcareous and marly—a mass of shells and small corals, passing occasionally into a soft building-stone. At Sudbourn, near Orford, where it assumes this character, are large quarries, in which the bottom of it has not been reached at the depth of fifty feet. At some places in the neighbourhood, the softer mass is divided by thin flags of hard limestone, and corals placed in the upright position in which they grew.

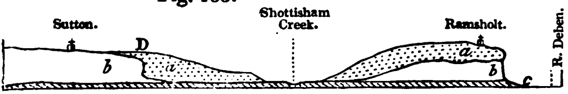
The Red crag is distinguished by the deep ferruginous or ochreous colour of its sands and fossils, the coralline by its white colour. Both formations are of moderate thickness; the red crag rarely exceeding forty, and the coralline seldom amounting to twenty, feet. But their importance is not to be estimated by the density of the mass of strata, or its geographical extent, but by the extraordinary richness of its organic

* See Paper by E. Charlesworth, Esq.; London and Ed. Phil. Mag. No. xxxviii. p. 81., Aug. 1835.

remains, belonging to a very peculiar type, which seems to characterize the state of the living creation in the north of Europe during the last part of the Miocene era.

For a large collection of the fish, echinodermata, shells, and corals of the deposits in Suffolk, we are indebted to the labours of Mr. Searles Wood. Of testacea alone he has obtained about 230 species from the Red, and 345 from the Coralline crag, about 150 being common to each. The proportion of recent species in the newer group has been found to be about 30 per cent., and that in the older or coralline, about 20. Whenever the two divisions are met with in the same district, the red crag lies uppermost; and, in some cases, as in the section represented in Fig. 133, it is observed that

Fig. 133.



Section near Ipswich, in Suffolk.

a. Red crag. *b.* Coralline crag. *c.* London clay.

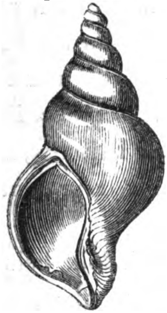
the older or coralline mass *b* had suffered denudation before the newer formation *a* was thrown down upon it. At D there is not only a distinct cliff, eight or ten feet high, of coralline crag, running in a direction N. E. and S.W., against which the red crag abuts with its horizontal layers; but

this cliff occasionally overhangs. The rock composing it is drilled everywhere by *Pholades*, the holes which they perforated having been afterwards filled and covered over when the newer sandy beds were thrown down. Such a cliff may have been caused by submarine denudation, in a shallow sea; and, had the red crag been equally solid, it would probably have presented many similar perpendicular cliffs; for beds, ten or twelve feet thick, of loam or sand, in this formation, are often seen to be unconformable to older beds, which have been in part cut away. The layers of sand in this upper or Red crag often resemble those of a shifting sand bank; for they are inclined diagonally, and the planes of stratification are sometimes directed in the same quarry to the four cardinal points of the compass, as at Butley. That here, and in many other localities, this structure has not been due, to any subsequent rearrangement of particles, is proved by each bed being made up of flat pieces of shell which lie parallel to the planes of the smaller strata.

Some fossils, which are very abundant in the Red crag, have never been found in the white or Coralline division; as, for example, the *Fusus contrarius* (Fig. 134.), and several species of *Buccinum* or *Nassa*, and *Murex*. (See Figs. 135, 136.), which two genera seem never to have been discovered in the lower crag.

Fossils characteristic of the Red Crag.

Fig. 134.



Fusus contrarius.

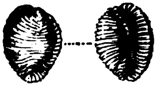
Fig. 135.

Murex alveolatus.

Fig. 136.

Nassa granulata.

Fig. 137.



Cypræa coccinelloides.

Fig. 134. half nat. size; the others nat. size.

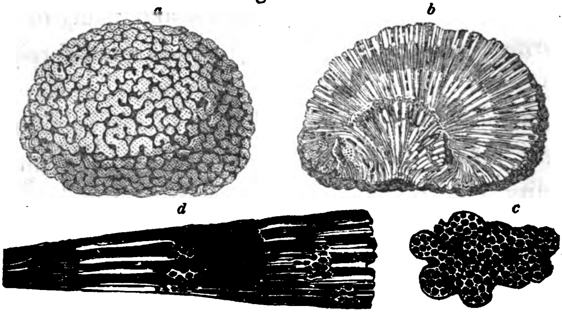
Among the bones and teeth of fishes are those of large sharks (*Carcharias*), and a gigantic skate of the extinct genus *Myliobates*, and many other forms, some common to our seas, and many foreign to them.

The distinctness of the fossils of the Coralline crag arises, doubtless, in part from higher antiquity, but, in some degree, also, from a difference in the geographical conditions of the submarine bottom. The prolific growth of corals, echini, and a prodigious variety of testacea, implies a region of deep and tranquil water; whereas, the red crag may have been formed afterwards on the same spot, when the water was shallower and more frequently turbid. In the mean time the climate may have become somewhat cooler, many of the stone-building zoophytes which flourished in the

first period may have disappeared, and hence the fauna of the Red crag may have acquired a character more nearly resembling that of our northern seas, as is implied by the large development of certain sections of the genera *Fusus*, *Buccinum*, *Purpura*, and *Trochus*, proper to higher latitudes, and which are wholly wanting or feebly represented in the inferior crag.

The corals of the lower crag of Suffolk belong in great part to genera unknown in the living creation, and are of a very peculiar structure; as, for example, that represented in the annexed Fig. (138.), which is one of several species having a

Fig. 138.



Fascicularia aurantium, Milne Edwards. Family, *Tubuliporidæ*, of same author.

Coral of extinct genus, from the inferior or coralline crag, Suffolk.

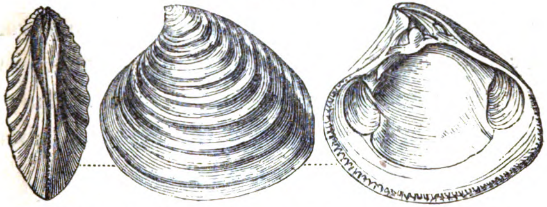
a. exterior. *b.* vertical section of interior.

c. portion of exterior magnified.

d. portion of interior magnified, showing that it is made up of long, thin, straight tubes, united in conical bundles.

globular form. The great number and variety of these zoophytes probably indicate an equable climate, free from intense cold in winter. On the other hand, that the heat was never excessive is confirmed by the prevalence of northern forms among the testacea, such as the *Glycimeris*, *Cyprina*, and *Astarte*. Of the genus last mentioned (see Fig. 139.) there are about fourteen

Fig. 139.



Astarte (*Crassina*, Lam.); *species common to upper and lower crag.*

species, many of them being rich in individuals; and there is an absence of genera peculiar to hot climates, such as *Conus*, *Oliva*, *Mitra*, *Fasciolaria*, *Crassatella*, and others. The cowries (*Cypræa*, Fig. 137.), also, are small, and belong to a section (*Trivia*) now inhabiting the colder regions. A large volute, called *Voluta Lamberti* (Fig. 140.), may seem an exception; but it differs in form from the volutes of the torrid zone, and may, like the living *Voluta Ma-*

Fig. 140.

Voluta Lamberti, young individ.

gellanica, have been fitted for an extra-tropical climate.

The occurrence, however, of a species of *Lingula* at Sutton, is worthy of remark, as these *Brachiopoda* seem now confined to more equatorial latitudes, and the same may be said still more decidedly of a species of *Pyrula*, allied to *P. reticulata*. Whether, therefore, we may incline to the belief that the mean annual temperature was higher or lower than now, we may at least infer that the climate and geographical conditions were very distinct at the period of the Suffolk crag from those now prevailing in the same region; a conclusion in harmony with the fact, that about four fifths of the testacea are extinct.

Out of sixteen species of echinodermata found in the lower crag by Mr. Wood, none agree with the recent, so far as our present knowledge extends. Some of the forms, as the *Echinus*, now exist in the neighbouring sea; some are, according to M. Agassiz, peculiar; and some now only known in warmer latitudes.

Strata containing fossil shells, like those of the Suffolk crag, above described, have been found near Antwerp; and lately (1840) I observed a small patch of them near Valognes in Normandy. There is another deposit, also containing similar fossils, at St. George Bohon, and other places a few leagues to the S. of Ca-

rentan; but they have never been traced farther southwards.

Faluns of Touraine. — Near the towns of Dinan and Rennes, in Brittany, and again in the provinces bordering the Loire, a tertiary formation, containing another assemblage of fossils, is met with, to which the name of *Faluns* has been long given by the French agriculturists, who spread the shelly sand and marl over the land, in the same manner as the crag was formerly much used in Suffolk. Isolated masses of these faluns occur from near the mouth of the Loire, near Nantes, as far as a district south of Tours. They are also found at Pontlevoy, on the Cher, about 70 miles above the junction of that river with the Loire, and 30 miles S.E. of Tours. They consist principally of sand and marl, in which are shells and corals, some entire, some rolled, and others in minute fragments. In certain districts, as at Doué, in the department of Maine and Loire, 10 miles S.W. of Saumur, they form a soft building-stone, chiefly composed of an aggregate of broken shells, corals, and echinoderms, united by a calcareous cement; the whole mass being very like the coralline crag near Aldborough and Sudbourn in Suffolk. The scattered patches of faluns are of slight thickness, rarely exceeding fifty feet; and between the district called Sologne and the sea they repose on a great variety of older rocks;

being seen to rest successively upon gneiss, clay-slate, and various secondary formations, including the chalk; and, lastly, upon the upper fresh-water limestone of the Parisian tertiary series, which, as before mentioned (p. 274.), stretches continuously from the basin of the Seine to that of the Loire.

At some points, as at Louans, south of Tours, the shells are stained of a ferruginous colour, not unlike that of the red crag of Suffolk. The species are, for the most part, marine, but a few of them belong to land and fluviatile genera. Among the former, *Helix turonensis* (Fig. 45. p. 65.) is the most abundant. Remains of terrestrial quadrupeds are here and there intermixed, belonging to the genera mastodon, rhinoceros, hippopotamus, deer, and others, and these are accompanied by cetacea, such as the lamantine, morse, sea-calf, and dolphin, all of extinct species.

Out of 290 species of shells, collected by myself, in 1840, at Pontlevoy, Louans, Bossée, and other villages 20 miles south of Tours; and at Savigné, about 15 miles north-west of that place; 72 are identical with recent species, which is in the proportion of 25 per cent. A large number of the 290 species are common to all the localities, those peculiar to each not being more numerous than we might expect to find in different bays of the same sea.

The total number of species from the faluns, in my possession, is 302, of which 45 only were found by Mr. Wood to be common to the Suffolk crag. The corals of the faluns are, in like manner, very dissimilar from those of the crag, if we regard them solely in reference to species; but their resemblance is considerable, if we direct our chief attention to their generic forms. The number of corals obtained by me át Doué, and other localities before adverted to, amounts to about 43, as determined by Mr. Lonsdale, of which seven agree specifically with those of the Suffolk crag. Only one has, as yet, been identified with living species. But it is difficult, if not impossible, to institute at present a satisfactory comparison between fossil and recent *Polyparia*, from the deficiency of our knowledge of the living species. Some of the genera occurring fossil in Touraine, as the *Astrea*, *Lunulites*, and *Dendrophyllia*, have not been found in European seas north of the Mediterranean; nevertheless, the *Polyparia* of the faluns do not indicate a climate much warmer than that which now prevails on the southern coasts of Europe.

It was stated that, on comparing about 300 species of Touraine shells with about 450 from the Suffolk crag, 45 only were found to be common to both, which is in the proportion of only 15 per cent., an amount of agreement

which is almost exactly the same as that found in the corals. Undoubtedly this amount is extremely small; although we must bear in mind that the numbers 300 or 450, above mentioned, represent fractions only of ancient faunas. It is like comparing a portion of the Mediterranean testacea with a part of those known in the British seas; and, for the sake of experiment, I requested Mr. G. Sowerby to examine 280 species of shells from the Mediterranean, and compare them with 600 of the best determined British species. Of these, 160 were found to be common to both collections, which is in the proportion of 57 per cent. This per centage, however, is raised by the greater extent of our knowlege of the British testacea, than of the Suffolk Miocene shells, of which we are only acquainted with 450 species. Admitting, however, that the fossils of the Faluns and the Crag depart much more widely from each other than do the British shells from those of the Mediterranean, it is still conceivable that those tertiary formations may have been contemporaneous, if the Crag was deposited in a sea opening to the north, and the Faluns in another opening to the south, a barrier of land existing between the two. The breadth of such a barrier could not have been great, because Suffolk and Touraine are not 300 miles distant from each other, and some patches of the Crag extend

south into Normandy, and others of the Faluns as far north as Rennes, in Brittany. But the isthmuses of Suez and Panama are also very inconsiderable, both in height and breadth, and yet the seas which they separate are inhabited by distinct testacea.

Other causes, however, may have co-operated powerfully with a geographical barrier to create a difference in the zoological productions of the neighbouring seas, of the faluns, and crag. Thus, for example, in the southern hemisphere at present, the transition is very sudden from a latitude enjoying a mild and equable climate, in which many tropical forms of testacea exist, to another where there is extreme cold, and where we may look for a fauna of an arctic character. Such a condition of things might have been almost as effectual as a strip of land, in preventing a free range of northern species towards the south, or of southern species towards the north.

In confirmation of this view, it should be remembered, that the assemblage of genera in the crag is somewhat anomalous, if compared with the present fauna of our temperate latitudes, containing, as we have seen, a mixture of northern and southern forms, such as we now observe in parts of the southern Atlantic. To a certain extent the same observation holds true in respect to the faluns of Touraine, where most of the shells do not depart

from the Mediterranean type, although a few would seem to imply a tropical climate. Among these may be mentioned some large species of the genera *Conus*, *Terebra*, *Pyrula*, *Fasciolaria*, *Cerithium*, and *Cardita*.

M. Desnoyers, in 1825, expressed an opinion that the faluns were of the same age as the English crag, to which he was led by a similarity of mineral composition, and the general analogy of the fossil shells and zoophytes, together with the perfect identity of certain species. I dissented at the time from this conclusion, seeing that the species of shells were in general so distinct; but I am now inclined to come round to the same views, since I have ascertained that both formations contain a similar proportion of shells (about one fourth), identical with those now living. In this, however, and in almost every instance, the word *contemporaneous* must be understood in a large and liberal sense in geology; and when we refer both the Faluns and the Crag to some part of the Miocene period, we may still conceive that there were shades of difference in their relative ages, like that already pointed out in the Red and Coralline divisions of the Suffolk crag.

Bordeaux. — A great extent of country between the Pyrenees and the Gironde is overspread by tertiary deposits, which have been more particularly studied in the environs of Bordeaux

and Dax, from whence about 700 species of shells have been obtained. A large proportion of these shells belong to the same zoological type as those of Touraine; but many are peculiar, and the whole may probably constitute an older division of the Miocene period than the faluns of the Loire. We must wait, however, for farther investigations, in order to decide this question with accuracy. The fossils figured in plate 3. are characteristic of the strata of Bordeaux and Dax.

Piedmont. — Many of the shells peculiar to the hill of the Superga, near Turin, agree with those found at Bordeaux and Dax; but the proportion of recent species is much less. The strata of the Superga consist of a bright green sand and marl, and a conglomerate with pebbles, chiefly of green serpentine, and are inclined at an angle of more than 70°. This formation, which attains a great thickness in the valley of the Bormida, is probably one of the oldest Miocene groups hitherto discovered.

Molasse of Switzerland. — If we cross the Alps, and pass from Piedmont to Savoy, we find there, at the northern base of the great chain, and throughout the lower country of Switzerland, a soft green sandstone much resembling some of the beds of the basin of the Bormida, above described, and associated in a similar manner with marls and conglomerate. This formation is called in Switz-

erland "molasse," said to be derived from "mol," "*soft*," because the stone is easily cut in the quarry. It is of vast thickness, and probably divisible into several formations. Whether all these may belong to the Miocene period cannot yet be determined, as fossil shells are often entirely wanting; but such as have been met with in a few places appear to bear out this conclusion, which is strongly corroborated by the agreement of the fossil fishes of the molasse and faluns. Among those common to both, M. Agassiz pointed out to me *Lamna contortidens*, *Myliobates Studeri*, *Spherodus cinctus*, *Notidanus primigenius*, and others. Some species of mammalia are also common to the molasse and faluns.

Lisbon.—Marine tertiary strata near Lisbon contain shells which agree very closely with those of Bordeaux, and are therefore referred to the Miocene era. Thus, out of 112 species collected by Mr. Smith, between 60 and 70 were found to be common to the strata of Bordeaux and Dax, the recent species being in the proportion of 21 per cent.

Styria.—Another important series of formations, found at the eastern extremity of the Alps in Styria, and which spread thence into the plains of Hungary, have also been referred to the same age. Nearest to the foot of the Alps appears the lowest of three natural groups, into which they

have been classed: it consists of sandstones, conglomerates, and marls, which are intersected by the rivers Mur, Raab, and Drave. The second group is characterized at Wildon by a coralline limestone not less than 400 ft. thick. In the third group, which occurs at a still greater distance from the mountains, beds of limestone are met with, which exhibit a perfectly oolitic structure. In the middle group, both in Styria and the basin of Vienna, the shells are considered to agree, on the whole, with the species of the Loire, Gironde, and other Miocene basins. How far the lowest and uppermost systems depart chronologically from the same type remains for future investigation.

Mayence. — The tertiary strata near Mayence contain in abundance the *Mytilus Brardii* (Fig. 141.), and several other characteristic Miocene fossils. They occupy a tract from five to twelve miles in breadth, extending along the left bank of the Rhine from Mayence to the neighbourhood of Manheim, and are again found to the east, north, and south-west of Frankfort. In some places they have the appearance of a freshwater formation; but in others, as at Alzey, the shells are for the most part marine. *Cerithia* are in great profusion, which indicates that the sea where the deposit was formed was fed by rivers; and the great quantity of fossil land shells, chiefly of the genus *Helix*,

Fig. 141.

Mytilus Brardii.

confirm the same opinion. The variety in the species of shells is small, scarcely eighty having yet been discovered, according to Professor Bronn, of Heidelberg, while the individuals are exceedingly numerous; a fact which accords perfectly with the idea that the formation may have originated in a gulf or sea which, like the Baltic, was brackish in some parts, and almost fresh in others. A species of *Paludina* (Fig. 142.), very nearly resembling the recent *Littorina ulva*, is found throughout this basin. These shells are like grains of rice in size, and are often in such quantity as to form entire beds of marl and limestone. They are as thick as grains of sand, in stratified masses from 15 to 30 ft. in thickness.

Fig. 142.

Paludina. Mayence.

It is most probable that the sandy beds of Eppelsheim are of the same age. In these the bones of several mammalia, and, among others, *Mastodon arvernensis*, and the new genus *Dinotherium*, have been met with. To the Miocene period we may also refer several detached lacustrine formations of Bavaria and Wurtemburg, and, among others, the freshwater beds of Georges Gemund, where, as in Touraine, we find an association of the genera Palæotherium, Mastodon, and Rhinoceros; the deposits of Osnabruck and other parts of Westphalia, and others, of wide extent, in Volhynia and Podolia, appear, also, to agree, by their fos-

sils, with the Miocene strata of Bordeaux and Touraine.

Upper Val d'Arno. — There are a great number of isolated tertiary formations, of freshwater origin, resting on primary and secondary rocks in different parts of Europe, in the same manner as we now find small lakes scattered over our continents and islands, wherein deposits are forming, quite detached from all contemporary marine strata. To determine the age of such groups, with reference to the great chronological series established for the marine formations, must often be a matter of difficulty; since we have not always an opportunity of ascertaining what freshwater shells may have been contemporary with certain sets of marine species.

The deposit of the Upper Val d'Arno, near Florence, in Tuscany, presents an example of one of these detached lacustrine groups, in which shells of the genera *Anodon*, *Paludina*, and *Neritina*, of species not known as recent, have been found associated with teeth and skeletons of extinct species of bear, weasel, wolf, fox, hyæna, beaver, elephant, mastodon, tapir, horse, pig, rhinoceros, hippopotamus, deer, ox, buffalo, and other quadrupeds. Some of the above mammalia agree specifically with fossils known elsewhere to belong to the Miocene period.

CHAPTER XV.

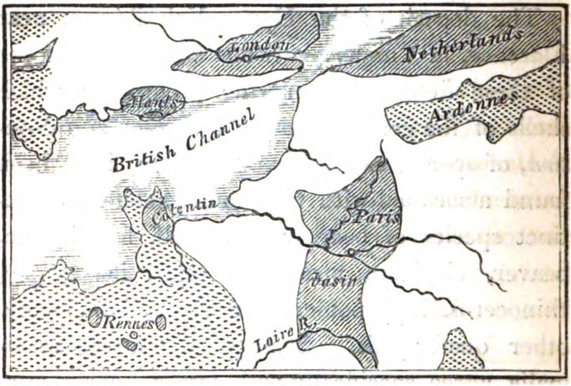
EOCENE FORMATIONS.

Position of London clay — Its fossils — Freshwater strata of Hants — Fossil mammalia — Strata of Kyson in Suffolk — Fossil monkey — Successive marine and freshwater formations in the Paris basin — Calcaire grossier — Calcaire siliceux — Gypsum — Fossil quadrupeds — Upper marine sand — Fossil shells.

English Eocene formations.—The accompanying map will explain to the student the position of

MAP OF THE PRINCIPAL TERTIARY BASINS OF THE EOCENE PERIOD.

Fig. 143.



Primary rocks and strata older than the carboniferous series.

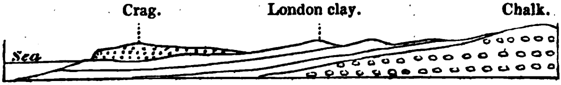
Eocene formations.

N.B. The space left blank is occupied by secondary formations from the old red sandstone to the chalk inclusive.

the principal Eocene formations of England, the Netherlands, and France. Those of England, it will be seen, are confined to two districts, usually called the basins of London and Hampshire. (See also Map, Plate 6.) These tracts are bounded by rising grounds, composed of chalk, except where the sea intervenes. That the chalk passes beneath the tertiary strata, as represented in Fig. 163. p. 387., we can not only infer from geological data, but can prove by numerous artificial sections at points where railways have been cut, wells sunk, or borings made, through the overlying beds.

In the section already given of the tertiary strata of Suffolk (p. 319.), it will be seen that the crag *a b* rests on a formation called the London clay (*c*), which there consists of alternating beds of blue and brown clay, with many nodules of calcareous stone, used for Roman cement. This formation is well seen in the neighbouring cliffs of Harwich, where the nodules contain many marine shells, and sometimes the bones of turtles. The relative position of the chalk, London clay,

Fig. 144.



and crag, between the coast of Essex and the interior, may be understood by reference to the annexed diagram.

The Eocene strata of the London basin are very simple in their composition, consisting almost entirely of clay, sand, and shingle, from 200 to 600 feet in thickness. They have generally been divided into three groups, though by a very arbitrary classification; the uppermost of which has been called the Bagshot sand, the second the London clay, and the lowest the plastic clay and sand. In the first of these, composed of siliceous sand and sandstone, and some beds of marl, fossils are very rare; but the teeth of *Pristis*, or saw-fish, sharks, rays, and other species, brought to light in a railway cutting made in 1838, near Guildford, prove these sands to agree closely in age with the London clay of the Isle of Sheppey, in which the same species are found.*

The blueish or dark argillaceous mass, called London clay, sometimes attains a thickness of 700 feet, as at High Beech, in Essex. Its stratification is often obscure. It frequently contains ovate nodules, or concretions of limestone, usually from a foot to 18 inches in diameter, which are traversed in various directions by cracks, dividing the whole into *septa*, or inclosures, whence the name septaria. These are sometimes continued through a thickness of 200 feet; and in some of them tes-

* Buckland, Proceedings of Geological Society, No. 58, p. 687.

tacea, fruits, and the entire shells of turtles have been met with.

The plastic clay and sand ought never to have been classed as a distinct formation, but merely as the inferior portion of the London clay; since, in one of the earliest publications on this subject, Mr. Webster pointed out, in the Isle of Wight, a distinct alternation of the sands of the lower part of the series with clay 200 feet thick, containing septaria, and replete with the usual fossils of the neighbourhood of London.* The plastic clay sometimes attains a thickness of from 400 to 500 feet. It is made up of an indefinite number of beds of sand, shingle, clay, and loam, irregularly alternating. Some of the clay being used in potteries, the name of plastic clay has been given to the whole formation. The beds of shingle are composed of perfectly rolled chalk-flints, with here and there small pebbles of quartz. Heaps of these materials appear sometimes to have remained for a long time covered by a tranquil sea. Dr. Buckland states that he observed a large pebble in part of this formation at Bromley, to which five full-grown oyster-shells were affixed, in such a manner as to show that they had com-

* See also Professor Sedgwick and Mr. Bowerbank in confirmation of this opinion, Phil. Mag. and Geol. Proceedings.

menced their first growth upon it, and remained attached through life.*

The fossils of these Eocene strata differ almost entirely from those of the crag. Out of 400 species of shells, scarcely any can be identified with those now living. Upon the whole, they resemble the testaceous fauna of the tropics; a conclusion favoured by the occurrence of many species of *Conus*, *Mitra* and *Voluta*, a large *Cypræa*, a very large *Rostellaria*, and shells of the genera *Terebellum*, *Cancellaria*, *Crassatella*, and others, with four or more species of *Nautilus*. (See Figures, p. 341.) There are fish, also, which indicate a warm climate; among which may be mentioned a sword-fish (*Tetrapterus priscus*, Agassiz), about eight feet long, and a saw-fish (*Pristis bisulcatus*, Ag.), about ten feet in length; genera foreign to the British seas.

These fossils have been found in the island of Sheppey, which is composed of London clay, where also, as I learn from M. Agassiz, the remains of no less than fifty other species of fish have been discovered.

An immense number of fruits and seeds of plants, penetrated with iron pyrites, have been procured from the clay of Sheppey, belonging, it is supposed, to more than 700 distinct species.

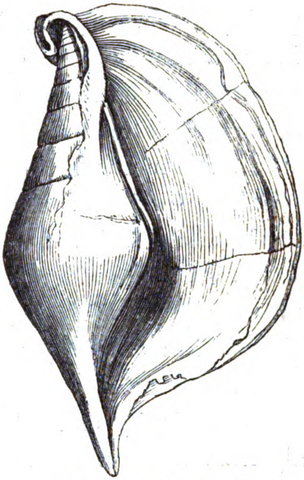
* Geological Transactions, 1st Series, Vol. iv. p. 300.

FOSSIL SHELLS OF THE LONDON CLAY.

Fig. 145.

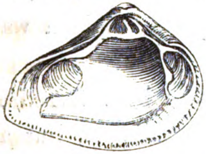
Mitra scabra.

Fig. 146.



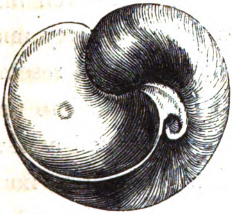
Rostellaria macroptera, Sow. one-third of nat. size.

Fig. 147.



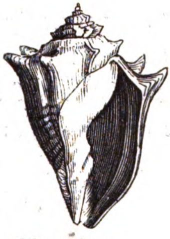
Crassatella sulcata.

Fig. 148.



Nautilus centralis.

Fig. 149.



Voluta athleta.

Fig. 150.

Terebellum fusiforme.

Mr. Bowerbank, in a valuable publication devoted to the description of these fossils, has shown that many of them are decidedly referable to families

of plants now confined to tropical regions. He has described thirteen fruits of palm of the recent type *Nipa*, now only found in the Molucca and Philippine islands. These plants are allied to the cocoa-nut tribe on the one side, and on the other to the *Pandanus*, or screw-pine. Species of cocoa-nuts are also met with, and other kinds of palms; also three species of *Anona*, or custard-apple; cucurbitaceous fruits, also (the gourd and melon family), are in considerable abundance. Fruits of various species of *Acacia*, are in profusion; and, although less decidedly tropical, imply a warm climate.

The contiguity of land may be inferred not only from these vegetable productions, but also from the teeth and bones of crocodiles and turtles, since these creatures, as Mr. Conybeare has remarked, must have resorted to some shore to lay their eggs. Very recently (1839) Mr. Owen has recognized among the fossils from Sheppey and Herne Bay the bones of a large serpent, resembling a *Boa* or *Python*, and a bird allied to the vultures, together with a quadruped of a new genus (*Hyracotherium*), allied to the hyrax, hog, and chæropotamus.

Freshwater strata of the Hampshire basin. — In the northern part of the Isle of Wight, and part of the opposite coast of Hampshire, freshwater strata occur resting on the London clay. They are

composed chiefly of calcareous and argillaceous marls, with a few layers of limestone, sometimes slightly siliceous. The marls are often green, and bear a considerable resemblance to certain green marls of Auvergne and the neighbourhood of Paris, which will afterwards be mentioned.

At Headon Hill, on the north side of Alum Bay, in the Isle of Wight, is a vertical precipice, where the horizontal freshwater strata are exposed for a thickness of 400 feet. About half way up in the cliff appear beds in which there is a mixture of marine and freshwater shells; implying a temporary return of the sea, before and after which the waters of a lake or some large river prevailed over the same area. In these formations *Gyrogonites*, or the fossil seed-vessels of *Chara* (see p. 67.), are frequent, and shells of the genera *Limnea*, *Planorbis*, *Melanopsis*, and *Paludina*. At Binstead, near Ryde, several quadrupeds, corresponding in genera, and, for the most part, in species, with the celebrated fossils of the gypsum near Paris, have been detected in the freshwater limestone. They belong to the genera *Palæotherium* (four species), *Anoplotherium* (two species), *Chæropotamus*, and *Dichobune*; which last, when the remains were first found at Binstead, was supposed to be a musk deer.*

* See Owen on the fossils found by Mr. Pratt and Rev. W. D. Fox, Geol. Proceed., No. 59. p. 1.

Strata of Kyson in Suffolk.—At Kyson, a few miles east of Woodbridge, is a bed of clay, twelve feet thick, beneath which is a deposit of yellow and white sand, the age of which is matter of considerable interest, in consequence of many peculiar fossils contained in it. The incumbent clay, which is devoid of fossils, can be shewn, by position, to underlie the red crag of Suffolk, and is probably a member of the Eocene formation. In this sand has been found the first example of a fossil quadrumanous animal discovered in Great Britain, namely, the teeth and part of a jaw, shewn by Mr. Owen to belong to a monkey of the genus *Macacus* (see fig. 151.). The mammiferous fossils, first met with in the same bed, were those of an opossum (*Didelphys*) and an insectivorous bat (see figs. 152. and 153.), together with many teeth of fishes of the shark family, some of new and peculiar

Fig. 151.

Molar of monkey (Maccaus).

Fig. 152.

Molar and part of jaw of opossum.

species, but two of them, according to M. Agassiz, agreeing with those found in the red

crag, namely, *Lamna contortidens* and an *Otodus*. More recently (1840) Mr. Colchester has obtained other mammalian relics from Kyson, among which Mr. Owen has recognized several teeth of the genus *Hyracotherium*, and the vertebræ of a large serpent, probably a *Boa*. As the remains both of the *Hyracotherium* and *Boa* have also been met with in the London clay, as before remarked, these fossils confirm the opinion previously entertained, that the Kyson sand belongs to the Eocene period. The *Macacus*, therefore, constitutes the first example of any quadrumanous animal found in strata as old as the Eocene, or in a latitude so far from the equator (52° N.). It was not until after the year 1836 that the existence of any fossil quadrumana were brought to light. Since that period they have been found in France, India, and Brazil. Those in France were procured at Sansan, near Auch, in the department of Gers, about forty miles west of Toulouse, in lat. 43° 40′ N., in freshwater strata, probably of the Miocene period. They were associated with the bones of the Dinotherium, Mastodon, Rhinoceros, and other mammifers.

Fig. 153.

Molars of insectivorous bats, twice nat. size.

Paris basin. — No formations can be more dissimilar in mineral character than the Eocene de-

posits of England and Paris; those of our own island being almost exclusively of mechanical origin,—accumulations of mud, sand, and pebbles; while in the neighbourhood of Paris we find strata inclosing a similar assemblage of organic remains, but composed partly of a coarse white limestone, and partly of a compact siliceous limestone of great thickness, with here and there intercalated beds of crystalline gypsum, or pure flint.

The area which has been called the Paris basin is about 180 miles in its greatest length from north-east to south-west, and about 90 miles from east to west. This space may be described as a depression in the chalk, which has been filled up by alternating groups of marine and freshwater strata. MM. Cuvier and Brongniart attempted, in 1811, to distinguish five different formations, comprising three freshwater and two marine, which alternated with each other. It was imagined that the waters of the ocean had been by turns admitted and excluded from the same region; but the subsequent investigations of several geologists, especially of M. Constant Prevost*, have led to great modifications in these theoretical views; and now that the true order of succession is better understood, it appears that several of the deposits, which were

* Bulletin des Sci. de la Soc. Philom., May, 1825., p. 74.

supposed to have originated one after the other, were, in fact, in progress at the same time by the joint action of the sea and rivers.

The order of superposition may be thus briefly expressed, beginning with the lowest beds: —

1st. Three formations of contemporaneous date, resting on the fundamental chalk, and, in some places, alternating with each other; namely, 1. freshwater beds, containing plastic clay and lignite: 2. marine limestone (calcaire grossier); 3. freshwater limestone (calcaire siliceux).

2dly. Marls and gypsum, with bones of quadrupeds, in part contemporaneous with the preceding, and in part posterior.

3dly. Upper marine sands.

4thly. Upper freshwater marls, with siliceous millstone.

Immediately upon the chalk there is usually a layer of broken chalk-flints, often cemented into a breccia by siliceous sand. These flints probably indicate the action of the sea upon reefs of chalk when a portion of that rock had emerged, and before the regular tertiary beds were superimposed.

Upon this flinty stratum, or, if it be wanting, upon the chalk itself, rests frequently a deposit of clay and lignite, which includes the remains of freshwater shells and drift-wood, and was, at first, regarded as a proof that the Paris basin had

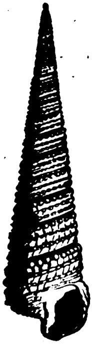
originally been filled with fresh water. But it has since been shown that strata of this character are of very partial extent, and have been repeated again and again in different parts of the overlying series. The phenomena, in fact, lead us simply to infer, that a river charged with argillaceous sediment entered a bay of the sea, and drifted into it, from time to time, freshwater shells and wood.

Calcaire grossier.—The formation called calcaire grossier consists of a coarse limestone, often passing into sand. It contains by far the greater number of the fossil shells which characterize the Paris basin. (See Pl. 4.) No less than 400 distinct species have been procured from a single spot near Grignon. They are imbedded in a calcareous sand, chiefly formed of comminuted shells, in which, nevertheless, individuals in a perfect state of preservation, both of marine, terrestrial, and freshwater species, are mingled together. Some of the marine shells may have lived on the spot; but the *Cyclostoma* and *Limnea* must have been brought thither by rivers and currents, and the quantity of triturated shells implies considerable movement in the waters.

Nothing is more striking in this assemblage of fossil testacea than the great proportion of species referable to the genus *Cerithium*. (See fig. 154.) There occur no less than 137 species of this genus

in the Paris basin, and almost all of them in the calcaire grossier. Now the living *Cerithia* inhabit the sea near the mouths of rivers, where the waters are brackish; so that their abundance in the marine strata now under consideration is in harmony with the hypothesis, that the Paris basin formed a gulf into which several rivers flowed, the sediment of some of which gave rise to the beds of clay and lignite before mentioned; while a distinct freshwater limestone, called calcaire siliceux, which will presently be described, was precipitated from the waters of others situated farther to the south.

Fig. 154.



*Cerithium cinctum.**

In some parts of the calcaire grossier round Paris, certain beds occur of a stone used in building, and called by the French geologists "Miliolite limestone." It is almost entirely made up of millions of microscopic shells, of the size of minute grains of sand, which all belong to the class Foraminifera. Figures of some of these are given in the annexed plate (Pl. 5.). As this miliolitic stone never occurs in the Faluns, or Miocene strata of Brittany and Touraine, it often furnishes the geologist with a useful criterion for distinguishing the de-

* This species is found both in the Paris and London basins.

tached Eocene and Miocene formations, scattered over those and other adjoining provinces.

Calcaire siliceux.—This compact siliceous limestone extends over a wide area. It resembles a precipitate from the waters of mineral springs, and is often traversed by small empty sinuous cavities. It is, for the most part, devoid of organic remains, but in some places contains freshwater and land species, and never any marine fossils. The siliceous limestone and the calcaire grossier occupy distinct parts of the Paris basin, the one attaining its fullest development in those places where the other is of slight thickness. They also alternate with each other towards the centre of the basin, as at Sergy and Osny; and there are even points where the two rocks are so blended together that portions of each may be seen in hand specimens. Thus, in the same bed, at Triel, we have the compact freshwater limestone, characterized by its *Limneæ*, mingled with the coarse marine limestone, through which the small multilocular shell, called milliolite, is dispersed in countless numbers. These microscopic testacea are also accompanied by *Cerithia* and other shells of the calcaire grossier. It is very extraordinary that in this instance both kinds of sediment must have been thrown down together on the same spot, and each has still retained its own peculiar organic remains.

From these facts we may conclude, that while to the north, where the bay was probably open to the sea, a marine limestone was formed, another deposit of freshwater origin was introduced to the southward, or at the head of the bay; for it appears that during the Eocene period, as now, the ocean was to the north, and the continent, where the great lakes existed, to the south. From that southern region we may suppose a body of fresh water to have descended, charged with carbonate of lime and silica, the water being perhaps in sufficient volume to freshen the upper end of the bay.

Gypsum and marls.—The next group to be considered consists of white and green marls, with gypsum. These were once supposed to be entirely subsequent in origin to the two groups already considered; but M. Prevost has pointed out that in some localities they alternate repeatedly with the calcaire siliceux, and in others with some of the upper members of the calcaire grossier. The gypsum, with its associated marl and limestone, is in greatest force towards the centre of the basin, where the two groups before mentioned are less fully developed: and M. Prevost infers, that while those two principal deposits were gradually in progress, the one towards the north, and the other towards the south, a

river descending from the east may have brought down the gypseous and marly sediment.

It must be admitted, as highly probable, that a bay or narrow sea, 180 miles in length, would receive, at more points than one, the waters of the adjoining continent. At the same time, we must be prepared to find that the simultaneous deposition of two or more sets of strata in one basin, some freshwater and others marine, must have produced very complex results. But, in proportion as it is more difficult in these cases to discover any fixed order of superposition in the associated mineral masses, so also is it more easy to explain the manner of their origin, and to reconcile their relations to the agency of known causes. Instead of the successive irruptions and retreats of the sea, and changes in the chemical nature of the fluid, and other speculations of the earlier geologists, we are now simply called upon to imagine a gulf, into one extremity of which the sea entered, and at the other a large river, while other streams may have flowed in at different points, whereby an indefinite number of alternations of marine and freshwater beds would be occasioned.

The gypsum occurs in the form of a saccharoid rock, in the hill of Montmartre at Paris, and other central parts of the basin. Although the lower beds of it alternate with the marine calcaire grossier,

it must be considered on the whole as a freshwater formation, as it contains land and fluviatile shells, together with fragments of palm wood, and great numbers of skeletons of quadrupeds and birds; an assemblage of organic remains, on which the anatomical labours of Cuvier have conferred great celebrity. The bones of freshwater fish, also, and of crocodiles, and many other reptiles, both land and fluviatile, occur in this rock. The skeletons of mammalia are usually isolated, often entire, the most delicate extremities being preserved; as if the carcasses, clothed with their flesh and skin, had been floated down soon after death, and while they were still swoln by the gases generated by their first decomposition. The few accompanying shells are of those light kinds which frequently float on the surface of rivers, together with wood.

M. Prevost has therefore suggested that a river may have swept away the bodies of animals, and the plants which lived on its borders, or in the lakes which it traversed, and may have carried them down into the centre of the gulf into which flowed the waters impregnated with sulphate of lime. We know that the Fiume Salso in Sicily enters the sea so charged with various salts that the thirsty cattle refuse to drink of it. A stream of sulphureous water, as white as milk, descends into the sea from the volcanic mountain of Idienne, on the east of Java; and a great body

of hot water, charged with sulphuric acid, rushed down from the same volcano on one occasion, and inundated a large tract of country, destroying, by its noxious properties, all the vegetation.* In like manner the Pusanibio, or "Vinegar River," of Colombia, which rises at the foot of Puracé, an extinct volcano, 7,500 feet above the level of the sea, is strongly impregnated with sulphuric and muriatic acids and with oxide of iron. We may easily suppose the waters of such streams to have properties noxious to marine animals, and in this manner the entire absence of marine remains in the ossiferous gypsum may be explained.†

There are no pebbles or coarse sand in the gypsum; a circumstance which agrees well with the hypothesis that these beds were precipitated from water holding sulphate of lime in solution, and floating the remains of different animals. The bones of land quadrupeds, however, are not confined entirely to the freshwater formation, to which the gypsum belongs; for the remains of a Palæotherium, together with some freshwater shells, have been found in a marine stratum belonging to the calcaire grossier at Beauchamp.

* Leyde Magaz. voor Wetensch Konst en Lett., partie v. cahier i. p. 71. Cited by Rozet, Journ. de Géologie, tom. i. p. 43.

† M. C. Prevost, Submersions Itératives, &c. Note 23.

In the gypsum the remains of about fifty species of quadrupeds have been found, all extinct, and nearly four-fifths of them belonging to a division of the order Pachydermata, which is now represented by only four living species; namely three tapirs and the daman of the Cape. With them a few carnivorous animals are associated, among which are a species of fox and gennet. Of the *Rodentia*, a dormouse and a squirrel; of the *Insectivora*, a bat; and of the *Marsupialia* (an order now confined to America, Australia, and some contiguous islands), an opossum, have been discovered.

Of birds, about ten species have been ascertained, the skeletons of some of which are entire. None of them are referable to existing species.* The same remark applies to the fish, according to MM. Cuvier and Agassiz, as also to the reptiles. Among the last are crocodiles and tortoises of the genera *Emys* and *Trionix*.

The tribe of land quadrupeds most abundant in this formation is such as now inhabits alluvial plains and marshes, and the banks of rivers and lakes, a class most exposed to suffer by river inundations. Whether the disproportion of carnivorous animals can be ascribed to this cause, or whether they were comparatively small in number

* Cuvier, Oss. Foss., tom. iii. p. 255.

and dimensions, as in the indigenous fauna of Australia, when first known to Europeans, is a point on which it would be rash, perhaps, to offer an opinion in the present state of our knowledge.

Upper marine and upper freshwater formations.—In addition to the several formations already enumerated, there are still two others, one usually called the upper marine, and the other the third or upper freshwater, which do not seem to have been going on simultaneously with the preceding groups. It seems probable that the deposits of the Paris basin, before described, had subsided to a certain extent, so that the sea prevailed exclusively for a time, and a deposit, chiefly formed of micaceous and quartzose sand, eighty feet thick, with marine shells, was superimposed on the older formations. After this subsidence, and when, perhaps, the gulf or estuary had been silted up with sand, another freshwater formation was superimposed. At this period a great number of marshes and shallow lakes seem to have existed, like those which frequently overspread the newest parts of great deltas. In these lakes many layers of marl, with beds of flint or of siliceous nodules, were formed, and *Charæ*, plants which now grow in the English lakes, and at considerable depths at the bottom of the great lakes of northern Italy, left their stems and seed-vessels, which are imbedded both in marl and flint, together with freshwater

shells. Some of the siliceous rocks of this formation are used extensively for millstones.

That oscillations of level occurred before the deposition of the upper marine formation seems confirmed by the fact that rolled blocks of calcaire grossier and calcaire siliceux, pierced by perforating shells belonging to no less than fifteen species, have been found in the upper marine sand. This reduction of portions of the older rocks, some of them freshwater, into fragments, implies that they had been exposed to denudation before some of the newer strata, in which the drilled blocks are now buried, were thrown down. The country may have risen in one part while it was depressed in another, as happened in the delta of the Indus in the year 1819.

Between the gypsum of the Paris basin and the upper marine sands a thin bed of oysters is found, which is spread over a remarkably wide area. From the manner in which they lie, it is inferred that they did not grow on the spot, but that some current swept them away from a bed of oysters formed in some other part of the bay. The strata of sand which immediately repose on the oyster-bed are quite destitute of organic remains; and nothing is more common in the Paris basin, and in other formations, than alternations of shelly beds with others entirely devoid of them. The temporary extinction and renewal of animal

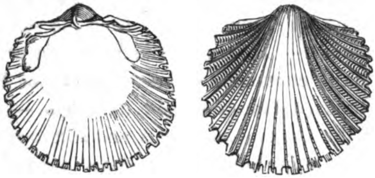
life at successive periods have been rashly inferred from such phenomena, which may nevertheless be explained, as M. Prevost justly remarks, without appealing to any such extraordinary revolutions in the state of the animate creation. A current one day scoops out a channel in a bed of shelly sand and mud, and the next day, by a slight alteration of its course, ceases to prey upon the same bank. It may then become charged with sand unmixed with shells, derived from some dune, or brought down by a river. In the course of ages an indefinite number of transitions from shelly strata to those without shells may thus be caused.

Having now given a rapid sketch of the different groups of the Paris basin, I may observe generally that they all belong to the Eocene epoch, although the entire series must doubtless have required an immense lapse of ages for its accumulation. The shells of the different freshwater groups, constituting at once some of the lowest and uppermost members of the series, are nearly all referable to the same species, and the discordance between the marine testacea of the calcaire grossier and the upper marine sands is not considerable.

A curious observation has been made by M. Deshayes, in reference to the changes which one species, the *Cardium porulosum*, has under-

gone during the long period of its existence in the Paris basin. Different varieties of this *Cardium* are characteristic of different strata. In the older sand of the Soissonais (a marine formation underlying the regular beds of the calcaire grossier), this shell acquires but a small volume,

Fig. 155.



Cardium porulosum. Paris and London basins.

and has many peculiarities, which disappear in the lowest beds of the calcaire grossier. In these the shell attains its full size, and many distinctive characters, which are again modified in the uppermost beds of the calcaire grossier; and these last modifications of form are preserved throughout the whole of the "upper marine" series.*

* Coquilles caractérist. des Terrains, 1831.

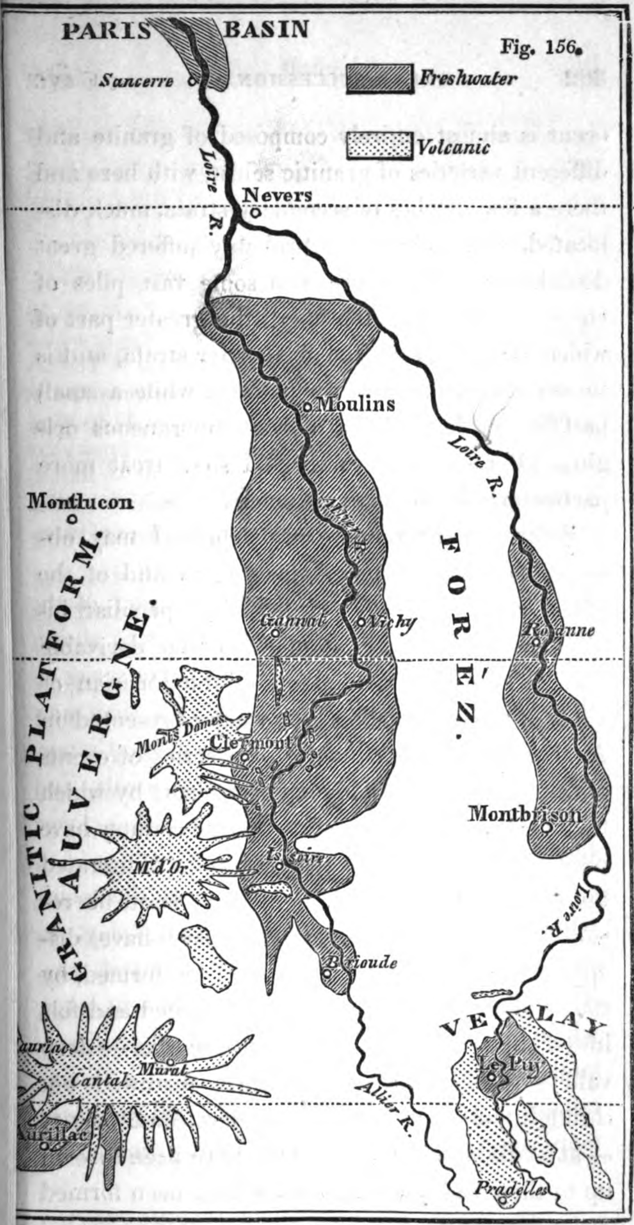
CHAPTER XVI.

EOCENE FRESHWATER FORMATIONS.

Lacustrine strata of Auvergne. — Great series of geographical changes since the land emerged from the sea. — Tertiary red sandstone. — Mineral character an uncertain test of age. — Marls containing Cypris. — Oolite of Eocene period. — Indusial limestone, and its origin. — Freshwater strata of the Cantal, calcareous and siliceous. — Resemblance of the white limestone and flints to chalk. — Various proofs of the gradual deposition of dense masses of strata.

In the account given in the last chapter of the tertiary strata of the Paris basin, it was shown that some members of that remarkable series of deposits were of freshwater origin. I shall now describe other formations in central France, which are very analogous in their fossils, and have been, in like manner, accumulated in large bodies of fresh water.

The strata alluded to are those of the lacustrine basins of Auvergne, Cantal, and Velay, the sites of which may be seen in the annexed map. They appear to be the monuments of ancient lakes, which, like some of those now existing in Switzerland, once occupied the depressions in a mountainous region, and have been each fed by one or more rivers and torrents. The country where they


PARIS BASIN
Fig. 156.
Sancerre
Freshwater
Volcanic
Loire R.
Nevers
47°
Moulins
Loire R.
Allier R.
Montluçon
GRANITIC PLATFORM.
AUVERGNE.
FOREZ.
Gannat
Vichy
Roanne
46°
Monts Domes
Clermont
Montbrison
M^t. d'Or
Issoire
Loire R.
Brioude
VELAY
Le Puy
Mauriac
Cantal
Murat
Allier R.
45°
Aurillac
Pradelles

occur is almost entirely composed of granite and different varieties of granitic schist, with here and there a few patches of secondary strata, much dislocated, and which have probably suffered great denudation. There are also some vast piles of volcanic matter (see the map), the greater part of which is newer than the freshwater strata, and is sometimes seen to rest upon them, while a small part has evidently been of contemporaneous origin. Of these igneous rocks I shall treat more particularly in the next volume.

Before entering upon any details, I may observe, that the study of this region and of the others above alluded to possesses a peculiar interest, very distinct in kind from that derivable from the investigation either of the Parisian or English tertiary strata. For we are presented in Auvergne with the evidence of a series of events of astonishing magnitude and grandeur, by which the original form and features of the country have been greatly changed, yet never so far obliterated but that they may still, in part at least, be restored in imagination. Great lakes have disappeared, — lofty mountains have been formed, by the reiterated emission of lava, preceded and followed by showers of sand and scoriæ, — deep valleys have been subsequently furrowed out through masses of lacustrine and volcanic origin, — at a still later date, new cones have been thrown up in these valleys, — new lakes have been formed

by the damming up of rivers—and more than one creation of quadrupeds, birds, and plants, have followed in succession; yet the region has preserved from first to last its geographical identity; and we can still recall to our thoughts its external condition and physical structure before these wonderful vicissitudes began, or while a part only of the whole had been completed. There was first a period when the spacious lakes, of which we still may trace the boundaries, lay at the foot of mountains of moderate elevation, unbroken by the bold peaks and precipices of Mont Dor, and unadorned by the picturesque outline of the Puy de Dome, or of the volcanic cones and craters now covering the granitic platform. During this earlier scene of repose deltas were slowly formed; beds of marl and sand, several hundred feet thick, deposited; siliceous and calcareous rocks precipitated from the waters of mineral springs; shells and insects imbedded, together with the remains of the crocodile and tortoise, the eggs and bones of water birds, and the skeletons of quadrupeds, some of them belonging to the same genera as those entombed in the gypsum of Paris. To this tranquil condition of the surface succeeded the era of volcanic eruptions, when the lakes were drained, and when the fertility of the mountainous district was probably enhanced by the igneous matter ejected from below, and poured

down upon the more sterile granite. During these changes, which appear to have taken place in the Miocene epoch, the mastodon, rhinoceros, elephant, tapir, hippopotamus, together with the ox, various kinds of deer, the bear, hyæna, and many beasts of prey, ranged the forest, or pastured on the plain, and were occasionally overtaken by a fall of burning cinders, or buried in flows of mud, such as accompany volcanic eruptions. Lastly, these quadrupeds became extinct, and gave place to the existing creation. There are no signs, during the whole time required for this series of events, of the sea having intervened, nor of any denudation which may not have been accomplished by currents in the different lakes, or by rivers and floods accompanying repeated earthquakes, during which the levels of the district have in some places been materially modified, and perhaps the whole upraised relatively to the surrounding parts of France.

Auvergne. — The most northern of the freshwater groups is situated in the valley-plain of the Allier, which lies within the department of the Puy de Dome, being the tract which went formerly by the name of the Limagne d'Auvergne. It is inclosed by two parallel primitive ranges, — that of the Forèz, which divides the waters of the Loire and Allier, on the east; and that of the Monts Domes, which separates the Allier from

the Sioule, on the west.* The average breadth of this tract is about twenty miles; and it is for the most part composed of nearly horizontal strata of sand, sandstone, calcareous marl, clay, and limestone, none of which observe a fixed and invariable order of superposition. The ancient borders of the lake, wherein the freshwater strata were accumulated, may generally be traced with precision, the granite and other ancient rocks rising up boldly from the level country. The actual junction, however, of the lacustrine and granitic beds is rarely seen, as a small valley usually intervenes between them. The freshwater strata may sometimes be seen to retain their horizontality within a very slight distance of the border-rocks, while in some places they are inclined, and in a few instances vertical. The principal divisions into which the lacustrine series may be separated are the following:—1st, Sandstone, grit, and conglomerate, including red marl and red sandstone. 2dly, Green and white foliated marls. 3dly, Limestone or travertin, often oolitic. 4thly, Gypseous marls.

1. *a. Sandstone and conglomerate.*—Strata of sand and gravel, sometimes bound together into a solid rock, are found in great abundance around the confines of the lacustrine basin, containing, in different places, pebbles of all the ancient rocks of

* Scrope, Geology of Central France, p. 15.

the adjoining elevated country; namely, granite, gneiss, mica-schist, clay-slate, porphyry, and others. But these strata do not form one continuous band around the margin of the basin, being rather disposed like the independent deltas which grow at the mouths of torrents along the borders of existing lakes.

At Chamalieres, near Clermont, we have an example of one of these deltas, or littoral deposits, of local extent, where the pebbly beds slope away from the granite, as if they had formed a talus beneath the waters of the lake near the steep shore. A section of about fifty feet in vertical height has been laid open by a torrent, and the pebbles are seen to consist throughout of rounded and angular fragments of granite, quartz, primary slate, and red sandstone; but without any intermixture of those volcanic rocks which now abound in the neighbourhood, and which could not have been there when the conglomerate was formed. Partial layers of lignite and pieces of wood are found in these beds.

At some localities on the margin of the basin quartzose grits are found; and, where these rest on granite, they are sometimes formed of separate crystals of quartz, mica, and felspar, derived from the disintegrated granite, the crystals having been subsequently bound together by a siliceous cement. In these cases the granite seems regene-

rated in a new and more solid form; and so gradual a passage takes place between the rock of crystalline and that of mechanical origin, that we can scarcely distinguish where one ends and the other begins.

In the hills called the Puy de Jussat and La Roche, we have the advantage of seeing a section continuously exposed for about 700 feet in thickness. At the bottom are foliated marls, white and green, about 400 feet thick; and above, resting on the marls, are the quartzose grits, cemented by calcareous matter, which is sometimes so abundant as to form imbedded nodules. These sometimes constitute spheroidal concretions six feet in diameter, and pass into beds of solid limestone, resembling the Italian travertins, or the deposits of mineral springs. This section is close to the confines of the basin; so that the lake must here have been filled up near the shore with fine mud, before the coarse superincumbent sand was introduced. There are other cases where sand is seen below the marl.

1. *b. Red marl and sandstone.*—But the most remarkable of the arenaceous groups is one of red sandstone and red marl, which are identical in all their characters with the secondary *New Red sandstone* and marl of England. In these secondary rocks the red ground is sometimes variegated with light greenish spots, and the same may be

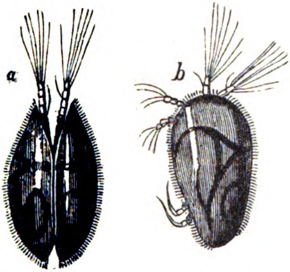
seen in the tertiary formation of freshwater origin at Coudes, on the Allier. The marls are sometimes of a purplish-red colour, as at Champheix, and are accompanied by a reddish limestone, like the well-known "cornstone," which is associated with the Old Red sandstone of English geologists. The red sandstone and marl of Auvergne have evidently been derived from the degradation of gneiss and mica-schist, which are seen *in situ* on the adjoining hills, decomposing into a soil very similar to the tertiary red sand and marl. We also find pebbles of gneiss, mica-schist, and quartz in the coarser sandstones of this group, clearly pointing to the parent rocks from which the sand and marl are derived. The red beds, although destitute themselves of organic remains, pass upwards into strata containing Eocene fossils, and are certainly an integral part of the lacustrine formation. From this example the student will learn how small is the value of mineral character alone, as a test of the relative age of rocks.

2. *Green and white foliated marls.* — The same primary rocks of Auvergne, which, by the partial degradation of their harder parts, gave rise to the quartzose grits and conglomerates before mentioned, would, by the reduction of the same materials into powder, and by the decomposition of their felpsar, mica, and hornblende, produce aluminous clay; and, if a sufficient quantity of car-

bonate of lime was present, calcareous marl. This fine sediment would naturally be carried out to a greater distance from the shore, as are the various finer marls now deposited in Lake Superior. And, as in the American lake, shingle and sand are annually amassed near the northern shores, so in Auvergne the grits and conglomerates before mentioned were evidently formed near the borders.

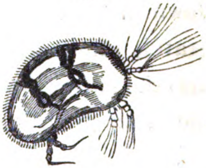
The entire thickness of these marls is unknown; but it certainly exceeds, in some places, 700 feet. They are, for the most part, either light-green or white, and usually calcareous. They are thinly foliated,—a character which frequently arises from the innumerable thin plates or scales of that small

Fig. 157.



Cypris unifasciata, a living species, greatly magnified.

Fig. 158.



Cypris vidua, a living species greatly magnified.*

a. Upper part. *b.* Side view of the same.

animal called *Cypris;* a genus which comprises several species, of which some are recent, and may

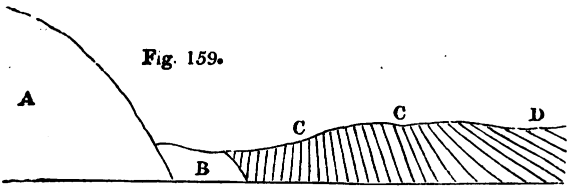
* See Desmarest's Crustacea, plate 55.

be seen swimming swiftly through the waters of our stagnant pools and ditches. The antennæ, at the end of which are fine pencils of hair, are the principal organs of motion, and are seen to vibrate with great rapidity. This animal resides within two small valves, not unlike those of a bivalve shell, and moults its integuments annually, which the conchiferous mollusks do not. This circumstance may partly explain the countless myriads of the shells of *Cypris* which were shed in the ancient lakes of Auvergne, so as to give rise to divisions in the marl as thin as paper, and that, too, in stratified masses several hundred feet thick. A more convincing proof of the tranquillity and clearness of the waters, and of the slow and gradual process by which the lake was filled up with fine mud, cannot be desired. But we may easily suppose that, while this fine sediment was thrown down in the deep and central parts of the basin, gravel, sand, and rocky fragments were hurried into the lake and deposited near the shore, forming the group described in the preceding section.

Not far from Clermont, the green marls, containing the *cypris* in abundance, approach to within a few yards of the granite which forms the borders of the basin. The occurrence of these marls so near the ancient margin may be explained by considering that, at the bottom of the ancient lake, no coarse ingredients were deposited in spaces intermediate

between the points where rivers and torrents entered, but finer mud only was drifted there by

Fig. 159.



Vertical strata of marl, at Champradelle, near Clermont.

A. Granite. B. Space of sixty feet, in which no section is seen.
C. Green marl, vertical and inclined. D. White marl.

currents. The *verticality* of some of the beds in the above section bears testimony to considerable local disturbance subsequent to the deposition of the marls; but such inclined and vertical strata are very rare.

3. *Limestone, travertin, oolite.* — Both the preceding members of the lacustrine deposit, the marls and grits, pass occasionally into limestone. Sometimes only concretionary nodules abound in them; but these, where there is an increase in the quantity of calcareous matter, unite into regular beds.

On each side of the basin of the Limagne, both on the west at Gannat, and on the east at Vichy, a white oolitic limestone is quarried. At Vichy, the oolite resembles our Bath stone in appearance and beauty; and, like it, is soft when first taken from the quarry, but soon hardens on exposure to

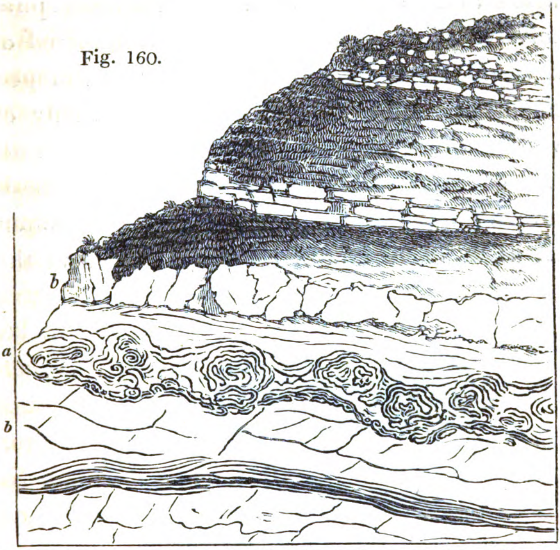
the air. At Gannat, the stone contains land-shells and bones of quadrupeds, resembling those of the Paris gypsum. At Chadrat, in the hill of La Serre, the limestone is pisolitic, the small spheroids combining both the radiated and concentric structure.

Indusial limestone. — There is another remarkable form of freshwater limestone in Auvergne, called "indusial," from the cases, or *indusiæ*, of caddis-worms (the larvæ of *Phryganea*); great heaps of which have been incrusted, as they lay, by carbonate of lime, and formed into a hard travertin. The rock is sometimes purely calcareous, but there is occasionally an intermixture of siliceous matter. Several beds of it are frequently seen, either in continuous masses, or in concretionary nodules, one upon another, with layers of marl interposed. The annexed drawing (Fig. 160.) will shew the manner in which one of these indusial beds (*a*) is laid open at the surface, between the marls (*b b*), near the base of the hill of Gergovia; and affords, at the same time, an example of the extent to which the lacustrine strata, which must once have filled a hollow, have been denuded, and shaped out into hills and valleys, on the site of the ancient lakes.

We may often observe in our ponds the *Phryganea* (or May-fly), in its caterpillar state, covered with small freshwater shells, which they have the

power of fixing to the outside of their tubular

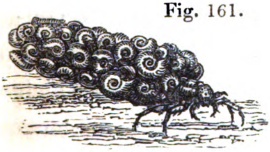
Fig. 160.



Bed of indusial limestone, interstratified with freshwater marl, near Clermont, (Kleinschrod).

cases, in order, probably, to give them weight and strength. The individual figured in the annexed cut, which belongs to a species very abundant in England, has happened to cover its case with shells of a small *Planorbis*. In the same manner a large species of caddis-worm, which swarmed in the

Fig. 161.

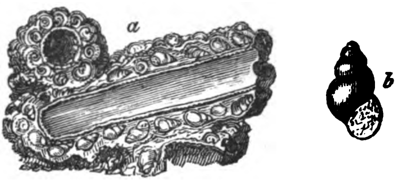


*Larva of recent Phryganea.**

* I believe that the British specimen here figured is *P. rhombica*, Linn.

Eocene lakes of Auvergne, was accustomed to attach to its dwelling the shells of a small spiral univalve of the genus *Paludina*. A hundred of these minute shells are sometimes seen arranged around one tube, part of the central cavity of which is often empty, the rest being filled up with thin concentric layers of travertin. The cases have been thrown together confusedly, and often lie, as in Fig. 162., at right angles one to the

Fig. 162.



a. Indusial limestone of Auvergne.
b. Fossil *Paludina* magnified.

other. When we consider that ten or twelve tubes are packed within the compass of a cubic inch, and that some single strata of this limestone are six feet thick, and may be traced over a considerable area, we may form some idea of the countless number of insects and mollusca which contributed their integuments and shells to compose this singularly constructed rock. It is unnecessary to suppose that the *Phryganeæ* lived on the spots where their cases are now found; they may have multiplied in the shallows near the

margin of the lake, or in the streams by which it was fed, and their cases may have been drifted by a current far into the deep water.

In the summer of 1837, when examining, in company with Dr. Beck, a small lake near Copenhagen, I had an opportunity of witnessing a beautiful exemplification of the manner in which the tubular cases of Auvergne were probably accumulated. This lake, called the Fuure-Soe, occurring in the interior of Seeland, is about twenty English miles in circumference, and in some parts 200 ft. in depth. Round the shallow borders an abundant crop of reeds and rushes may be observed, covered with the indusiæ of the *Phryganea grandis* and another species, to which shells are attached. The plants which support them are *Scirpus lacustris* and *Arundo phragmitis*, but chiefly the former. In summer, especially in the month of June, a violent gust of wind sometimes causes a current by which these plants are torn up by the roots, washed away, and floated off in long bands, more than a mile in length, into deep water. The *Cypris* swarms in the same lake; and calcareous springs alone are wanting to form extensive beds of indusial limestone, like those of Auvergne.

4. *Gypseous marls.* — More than fifty feet of thinly laminated gypseous marls, exactly resembling those in the hill of Montmartre, at Paris, are worked for gypsum at St. Romain, on the

right bank of the Allier. They rest on a series of green cypriferous marls which alternate with grit, the united thickness of this inferior group being seen, in a vertical section on the banks of the river, to exceed 250 feet.

General arrangement and origin of the freshwater formations of Auvergne.—The relations of the different groups above described cannot be learnt by the study of any one section; and the geologist who sets out with the expectation of finding a fixed order of succession may perhaps complain that the different parts of the basin give contradictory results. The arenaceous division, the marls, and the limestone, may all be seen in some places to alternate with each other; yet it can, by no means, be affirmed that there is no order of arrangement. The sands, sandstone, and conglomerate, constitute in general a littoral group; the foliated white and green marls, a contemporaneous central deposit; and the limestone is for the most part subordinate to the newer portions of both. The uppermost marls and sands are more calcareous than the lower; and we never meet with calcareous rocks covered by a considerable thickness of quartzose sand or green marl. From the resemblance of the limestones to the Italian travertins, we may conclude that they were derived from the waters of mineral springs,—such springs as even now exist in Auvergne, and which may

be seen rising up through the granite, and precipitating travertin. They are sometimes thermal, but this character is by no means constant.

It seems that, when the ancient lake of the Limagne first began to be filled with sediment, no volcanic action had yet produced lava and scoriæ on any part of the surface of Auvergne. No pebbles, therefore, of lava were transported into the lake, — no fragments of volcanic rocks imbedded in the conglomerate. But at a later period, when a considerable thickness of sandstone and marl had accumulated, eruptions broke out, and lava and tuff were deposited, at some spots, alternately with the lacustrine strata. It is not improbable that cold and thermal springs, holding different mineral ingredients in solution, became more numerous during the successive convulsions attending this development of volcanic agency, and thus deposits of carbonate and sulphate of lime, silex, and other minerals, were produced. Hence these minerals predominate in the uppermost strata. The subterranean movements may then have continued until they altered the relative levels of the country, and caused the waters of the lakes to be drained off, and the farther accumulation of regular freshwater strata to cease.

We may easily conceive a similar series of events to give rise to analogous results in any modern basin, such as that of Lake Superior, for

example, where numerous rivers and torrents are carrying down the detritus of a chain of mountains into the lake. The transported materials must be arranged according to their size and weight, the coarser near the shore, the finer at a greater distance from land; but in the gravelly and sandy beds of Lake Superior no pebbles of modern volcanic rocks can be included, since there are none of these at present in the district. If igneous action should break out in that country, and produce lava, scoriæ, and thermal springs, the deposition of gravel, sand, and marl might still continue as before; but, in addition, there would then be an intermixture of volcanic gravel and tuff, and of rocks precipitated from the waters of mineral springs.

Although the freshwater strata of the Limagne approach generally to a horizontal position, the proofs of local disturbance are sufficiently numerous and violent to allow us to suppose great changes of level since the lacustrine period. We are unable to assign a northern barrier to the ancient lake, although we can still trace its limits to the east, west, and south, where they were formed of bold granitic eminences. Nor need we be surprised at our inability to restore entirely the physical geography of the country after so great a series of volcanic eruptions; for it is by no means improbable that one part of it, the

southern for example, may have been moved upwards bodily, while others remained at rest, or even suffered a movement of depression.

Cantal. — A freshwater formation, very analogous to that of Auvergne, is situated in the department of Haute Loire, near the town of Le Puy, in Velay, and another occurs near Aurillac, in Cantal. The leading feature of the formation last mentioned, as distinguished from those of Auvergne and Velay, is the immense abundance of silex associated with calcareous marls and limestone.

The whole series may be separated into two divisions; the lower, composed of gravel, sand, and clay, such as might have been derived from the wearing down and decomposition of the granitic schists of the surrounding country; the upper system, consisting of siliceous and calcareous marls, contains subordinately gypsum, silex, and limestone.

The resemblance of the freshwater limestone of the Cantal, and its accompanying flint, to the upper chalk of England, is very instructive, and well calculated to put the student upon his guard against relying too implicitly on mineral character alone as a safe criterion of relative age.

When we approach Aurillac from the west, we pass over great heathy plains, where the sterile mica-schist is barely covered with vegetation.

Near Ytrac, and between La Capelle and Viscamp, the surface is strewed over with loose broken flints, some of them black in the interior, but with a white external coating; others stained with tints of yellow and red, and in appearance precisely like the flint gravel of our chalk districts. When heaps of this gravel have thus announced our approach to a new formation, we arrive at length at the escarpment of the lacustrine beds. At the bottom of the hill which rises before us, we see strata of clay and sand, resting on mica-schist; and above, in the quarries of Belbet, Leybros, and Bruel, a white limestone, in horizontal strata, the surface of which has been hollowed out into irregular furrows, since filled up with broken flint, marl, and dark vegetable mould. In these cavities we recognize an exact counterpart to those which are so numerous on the furrowed surface of our own white chalk. Advancing from these quarries, along a road made of the white limestone, which reflects as glaring a light in the sun, as do our roads composed of chalk, we reach, at length, in the neighbourhood of Aurillac, hills of limestone and calcareous marl, in horizontal strata, separated in some places by regular layers of flint in nodules, the coating of each nodule being of an opaque white colour, like the exterior of the flinty nodules of our chalk.

It will be remembered that the siliceous stone of Bilin, called *tripoli*, is a freshwater deposit, and has been shown, by Ehrenberg, to be of infusorial origin (see p. 52.). What is true of the Bohemian flint and opal, where the beds attain a thickness of fourteeen feet, may also, perhaps, be found to hold good respecting the silex of Aurillac, which may also have been immediately derived from the minute cases of microscopic animalcules. But even if this conclusion be established, the abundant supply both of siliceous, calcareous, and gypseous matter, which the ancient lakes of France received, may have been connected with the subterranean volcanic agency of which those regions were so long the theatre, and which may have impregnated the springs with mineral matter, even before the great outbreak of lava. It is well known that the hot-springs of Iceland, and many other countries, contain silex in solution; and it has been lately affirmed, that steam at a high temperature is capable of dissolving quartzose rocks without the aid of any alkaline or other flux. *

Travellers not unfrequently mention, in their accounts of India, Australia, and other distant lands, that they have seen chalk with flints, which they have assumed to be of the same age as the Cretaceous system of Europe. A hasty observa-

* See Proceedings of Roy. Soc., No. 44. p. 233.

tion of the white limestone and flint of Aurillac might convey the same idea; but when we turn from the mineral aspect and composition to the organic remains, we find in the flints of the Cantal the seed-vessels of the freshwater *Chara*, instead of the marine zoophytes so abundantly imbedded in chalk flints; and in the limestone we meet with shells of *Limnea*, *Planorbis*, and other lacustrine genera, instead of the oyster, terebratula, and echinus of the Cretaceous period.

Proofs of gradual deposition. — Some sections of the foliated marls in the valley of the Cer, near Aurillac, attest, in the most unequivocal manner, the extreme slowness with which the materials of the lacustrine series were amassed. In the hill of Barrat, for example, we find an assemblage of calcareous and siliceous marls; in which, for a depth of at least sixty feet, the layers are so thin, that thirty are sometimes contained in the thickness of an inch; and when they are separated, we see preserved in every one of them the flattened stems of *Charæ*, or other plants, or sometimes myriads of small *Paludinæ* and other freshwater shells. These minute foliations of the marl resemble precisely some of the recent laminated beds of the Scotch marl lakes, and may be compared to the pages of a book, each containing a history of a certain period of the past. The different layers may be grouped together in beds from a

foot to a foot and a half in thickness, which are distinguished by differences of composition and colour, the tints being white, green, and brown. Occasionally there is a parting layer of pure flint, or of black carbonaceous vegetable matter, about an inch thick, or of white pulverulent marl. We find several hills in the neighbourhood of Aurillac composed of such materials, for the height of more than 200 feet from their base, the whole sometimes covered by rocky currents of trachytic or basaltic lava.*

Thus wonderfully minute are the separate parts of which some of the most massive geological monuments are made up! When we desire to classify, it is necessary to contemplate entire groups of strata in the aggregate; but if we wish to understand the mode of their formation, and to explain their origin, we must think only of the minute subdivisions of which each mass is composed. We must bear in mind how many thin leaf-like seams of matter, each containing the remains of myriads of testacea and plants, frequently enter into the composition of a single stratum, and how vast a succession of these strata unite to form a single group! We must remember, also, that piles of volcanic matter, like the Plomb du Cantal, which rises in the immediate

* Lyell and Murchison, sur les Dépôts Lacust. Tertiaires du Cantal, &c. Ann. des Sci. Nat. Oct. 1829.

neighbourhood of Aurillac, are themselves equally the result of successive accumulation, consisting of reiterated sheets of lava, showers of scoriæ, and ejected fragments of rock. — Lastly, we must not forget that continents and mountain-chains, colossal as are their dimensions, are nothing more than an assemblage of many such igneous and aqueous groups, formed in succession during an indefinite lapse of ages, and superimposed upon each other.

CHAPTER XVII.

CRETACEOUS GROUP.

White chalk — Its marine origin shown by fossil shells — Extinct genera of cephalopoda — Sponges and corals in the chalk — No terrestrial or fluviatile shells, no land plants — Supposed origin of white chalk from decomposed corals — Single pebbles, whence derived — Cretaceous coral-reef in Denmark — Maestricht beds and fossils — Origin of flint in chalk — Wide area covered by chalk — Green-sand formation and fossils — Origin of — Period of emergence from the sea — Difference of the chalk of the north and south of Europe — Hippurites — Nummulites — Altered lithological character of cretaceous formation in Spain and Greece — Terminology.

The group which succeeds to the tertiary strata in the descending order has been called Cretaceous or chalky, because it consists in part of that remarkable white earthy limestone called chalk (*creta*). With this limestone, however, are usually associated other deposits of sand, marl, and clay, called the Green-sand formation, because some of its sands are remarkable for their bright green colour.

The following is the manner in which the Cretaceous strata of the south of England have been subdivided: —

Cretaceous group.	1. Chalk formation.	a. soft white chalk, with flints	united thickness from 600 to 1000 feet.*
		b. hard white chalk, with few or no flints	
		c. chalk marl	
	2. Green-sand formation.	a. upper green-sand	thickness 30 to 100 feet.
		b. Gault, or blue marl,	10 to 150 ft.
		c. lower green-sand and iron-sand, with occasional limestone	250.†

The accompanying section (Fig. 163.) will show the manner in which the tertiary strata of the London and Paris basins, as they are called, rest upon the Chalk; and how the white chalk, in its turn, reposes throughout this region upon the Green-sand formation.

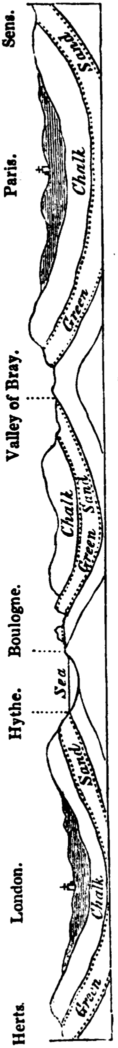
I shall now speak first of the Chalk, its fossils, and probable origin; and then say something of the Green-Sand; after which I shall point out the probable relations of the Chalk and Green-Sand to each other.

White Chalk.—The white chalk used in writing consists almost purely of carbonate of lime. Although usually soft, this substance passes in some districts, by a gradual change, into a solid stone used for building. The stratification is often obscure, except where rendered distinct by alternating layers of flint. These layers are from two to four feet distant from each other, and from three

* Conybeare, Outlines, &c., p. 85.

† Fitton, Geol. Trans., Second Series, vol. iv. p. 319.

Fig. 163.



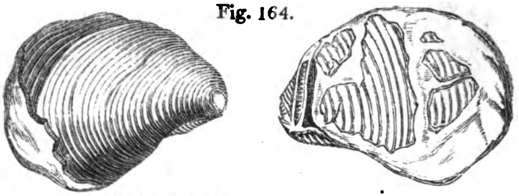
Section from Hertfordshire, in England, to Sens, in France.

to six inches in thickness, occasionally in continuous beds, but more frequently in nodules.

The annexed figures represent some few of the fossil shells which are abundant in the white chalk, and these alone are sufficient to prove its marine origin. Several of them, such as the *Terebratulæ* (see Figs. 168. 170, 171, 172.), are known to live at the bottom of the sea, where the water is tranquil and of some depth. The *Catillus* (Fig. 164.) may be pointed out as a form, which, so far as our present information extends, became extinct at the close of the cretaceous period, being never met with in any tertiary stratum, or in a living state. Among other equally conspicuous forms of fossil mollusca belonging to the cretaceous group, and foreign to the tertiary and recent periods, may be mentioned the *Belemnite*, *Ammonite*, *Baculite*, and *Turrilite* of the family *Cephalopoda*, to which the living Cuttle-fish and Nautilus belong.

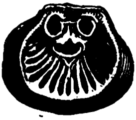
FOSSILS OF THE WHITE CHALK.

Fig. 164.



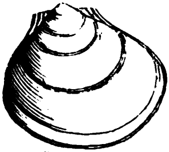
Catillus Cuvieri. (Syn. ***Inoceramus Cuvieri***, **Sow.)**

Fig. 165.



Crania Parisiensis, inferior or attached valve.

Fig. 166.

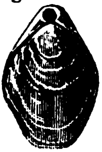


Plagiostoma Hoperi.

Fig. 167.

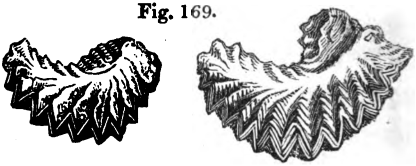
Plagiostoma spinosum.

Fig. 168.



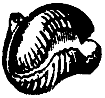
Terebratula Defrancii.

Fig. 169.



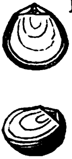
Ostrea carinata.
Chalk Marl and Upper Green-sand.

Fig. 170.



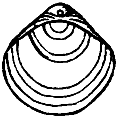
Terebratula octoplicata.
(*Var. of T. plicatilis.*)

Fig. 171.



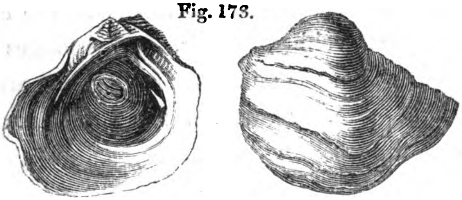
Terebratula pumilus.
(*Magas pumilus*, Sow.)

Fig. 172.



Terebratula carnea.

Fig. 173.



Ostrea vesicularis. (*Gryphæa globosa*, Sow.)
Also in Upper Green-sand.

FOSSIL CEPHALOPODA OF EXTINCT GENERA.

Cretaceous Period.

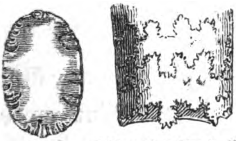
a Fig. 174. b

a. *Turrilites costatus.* Chalk-marl.
b. *Same, showing the indented border of the partition of the chambers.*

a Fig. 175. b

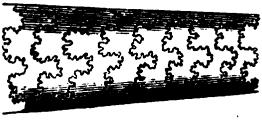
a. *Belemnites mucronatus.* } White Chalk and Upper Green-sand.
b. *Same, internal structure.* }

Fig. 176.



Portion of Baculites Faujasii.
White Chalk.

Fig. 177.

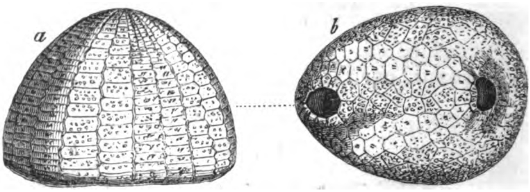


Portion of Baculites anceps.
White Chalk.

One of these, the *Belemnite*, like the bone of the common cuttle-fish, was an internal shell. Be-

sides these, there are other fossils in the chalk, such as sea-urchins, corals, and sponges (see Figures), which are alike marine. They are dispersed indifferently through the soft chalk and the hard flint.

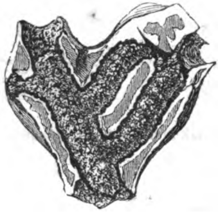
Fig. 178.



Ananchytes ovatus.

a. side view.
b. bottom of the shell, on which both the oral and anal apertures are placed; the anal being to the left, and more round.

Fig. 179. Fig. 180.

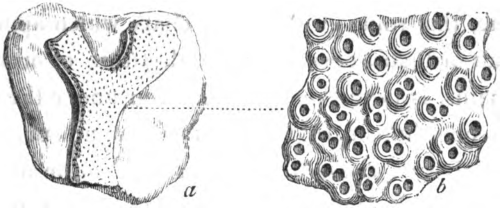


*A branching sponge in a flint from the chalk.**

To some of these inclosed zoophytes many flints owe their irregular forms, as in the flint represented in Fig. 180., where the hollows on the exterior are caused by the branches of a sponge,

* From the collection of Mr. Bowerbank.

Fig. 181.



Eschara disticha.

a. natural size. *b.* portion magnified.

which is seen on breaking open the flint. (See Fig. 179.)

With these fossils the remains of fishes and crustacea are not uncommon; but we meet with no bones of land animals, nor any terrestrial or fluviatile shells, nor any plants, except pieces of drift-wood and sea-weed, and scarcely ever any sand or pebbles. All the appearances concur in leading us to believe that this deposit was formed in a sea of some depth, far from land, and at a time when the fauna of this part of the globe was perfectly distinct from that of the tertiary period.

Origin of the White Chalk.—Having then come to the conclusion, that the chalk was formed in an open sea of some depth; we may next inquire, in what manner so large a quantity of this peculiar white substance could have accumulated over an area many hundred miles in diameter, and some of the extreme points of which are distant, as we shall see in the sequel, more than 1000 geographical miles from each other.

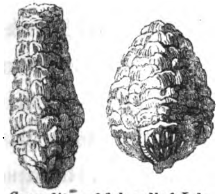
It was remarked in an early part of this volume, that some even of that chalk which appears to an ordinary observer quite destitute of organic remains, is nevertheless, when seen under the microscope, full of fragments of corals and sponges; the valves of *Cytherina*, the shells of foraminifera, and still more minute infusoria. (See p. 56.)

Now it had been often suspected, before these discoveries, that white chalk might be of animal origin, even where every trace of organic structure has vanished. This bold idea was partly founded on the fact, that the chalk consisted of pure carbonate of lime, such as would result from the decomposition of testacea, echini, and corals; and partly on the passage observable between these fossils when half decomposed and chalk. But this conjecture seemed to many naturalists quite vague and visionary, until its probability was strengthened by new evidence brought to light by modern geologists.

We learn from Lieutenant Nelson, that, in the Bermuda islands, there are several basins or lagoons almost surrounded and inclosed by reefs of coral. At the bottom of these lagoons a soft white calcareous mud is formed by the decomposition of *Eschara*, *Flustra*, *Cellepora*, and other corallines. This mud, when dried, is undistinguishable from common white earthy chalk; and some portions of it, presented to the Museum of

the Geological Society of London, might, after full examination, be mistaken for ancient chalk, but for the labels attached to them. About the same time Mr. C. Darwin observed similar facts in the coral islands of the Pacific; and came also to the opinion, that much of the soft white mud found at the bottom of the sea near coral reefs has passed through the bodies of worms, by which the stony masses of coral are everywhere bored; and other portions through the intestines of fishes; for certain gregarious fishes of the genus *Sparus* are visible through the clear water, browsing quietly, in great numbers, on living corals, like grazing herds of graminivorous quadrupeds. On opening their bodies, Mr. Darwin found their intestines filled with impure chalk. This circumstance is the more in point, when we recollect how the fossilist was formerly puzzled by meeting, in chalk, with certain bodies, called cones of the larch, which were afterwards recognized by Dr. Buckland to be the excrement of fish.* These spiral coprolites (see Figures), like the scales and bones of fossil fish in the chalk, are composed chiefly of phosphate of lime.

Fig. 182. Fig. 183.



Coprolites of fish called Iulo-eido-copri, from the chalk.

* Geol. Trans., Second Series, vol. iii. p. 232. plate 31. figs. 3. and 11.

Single pebbles in chalk.—The general absence of sand and pebbles in the white chalk has been already mentioned; but the occurrence here and there, in the south-east of England, of a few isolated pebbles of quartz and green-schist, some of them two or three inches in diameter, has justly excited much wonder. If these had been carried to the spots where we now find them by waves or currents from the lands once bordering the cretaceous sea, how happened it that no sand or mud were transported thither at the same time? We cannot conceive such rounded stones to have been drifted like erratic blocks by ice *, for that would imply a cold climate in the Cretaceous period; a supposition inconsistent with the luxuriant growth of large chambered univalves, numerous corals, and many fish, and other fossils of tropical forms.

Now in Keeling Island, one of those detached masses of coral which rise up in the wide Pacific, Captain Ross found a single fragment of greenstone, where every other particle of matter was calcareous; and Mr. Darwin concludes that it must have come there entangled in the roots of a large tree. He reminds us that Chamisso, the distinguished naturalist who accompanied Kotzebue, affirms, that the inhabitants of the Radack archipelago, a group of lagoon islands, in the midst of

* See Chapters x. and xi.

the Pacific, obtained stones for sharpening their instruments by searching the roots of trees which are cast up on the beach.*

It may perhaps be objected, that a similar mode of transport cannot have happened in the cretaceous sea, because fossil wood is very rare in the chalk. Nevertheless wood is sometimes met with, and in the same parts of the chalk where the pebbles are found, both in soft stone and in a silicified state in flints. In these cases it has often every appearance of having been floated from a distance, being usually perforated by boring-shells, such as the *Teredo* and *Fistulana*.†

The only other mode of transport which suggests itself is sea-weed. Dr. Beck informs me, that in the Lym-Fiord, in Jutland, the *Fucus vesiculosus* sometimes grows to the height of ten feet, and the branches rising from a single root, form a cluster several feet in diameter. When the bladders are distended, the plant becomes so buoyant as to float up loose stones several inches in diameter, and these are often thrown by the waves high up on the beach. The *Fucus giganteus* of Solander, so common in Terra del Fuego, is said by Captain Cook to attain the length of 360 feet, although the stem is not much thicker than a

* Darwin, p. 549. Kotzebue's First Voyage, vol. iii. p. 155.

† Mantell, Geol. of S. E. of England, p. 96.

man's thumb. It is often met with floating at sea, with shells attached, several hundred miles from the spots where it grew. Some of these plants, says Mr. Darwin, were found adhering to large loose stones in the inland channels of Terra del Fuego, during the voyage of the Beagle in 1834; and that so firmly, that the stones were drawn up from the bottom into the boat, although so heavy that they could scarcely be lifted in by one person.* Some fossil sea-weeds have been found in the Cretaceous formation, but none, as yet, of large size.

Cretaceous coral reef in Denmark.—Having said so much on the probable derivation of chalk from the decay of corals and shells, I may add, that in the island of Seeland, in Denmark, there is a yellow limestone intimately connected with the chalk, and containing a vast number of the same fossils, which consists of an aggregate of corals, retaining their forms as distinctly as the dead zoophytes which enter into the structure of reefs now growing in the sea. The thickness of this rock is unknown, but it has been quarried at Faxoe to the depth of forty feet. At Stevensklint, in Seeland, it is seen to rest on white chalk with flints, from which it differs greatly in appearance, and where it is covered again by another limestone, which,

* Darwin, p. 303. (For full reference see p. 168.)

although of later date, agrees more nearly with the white chalk, both in fossils and mineral character. Out of 104 species of sponges, corals, and other zoophytes, collected from the limestone of Faxoe, and from the ordinary white chalk of Denmark, which agrees with that of England, no less than forty-two are common to both formations; and many of the same species of bivalve shells and echinodermata have been found in both. The Faxoe formation, however, is not only remarkable for the number and good preservation of its fossil corals, but also from the generic resemblance of many of its univalve shells to forms usually supposed to appertain chiefly or exclusively to the tertiary period. Thus, among the patelliform univalves, we find *Patella* and *Emarginula*, and among the spiral the following genera, *Cypræa*, *Oliva*, *Mitra*, *Cerithium*, *Fusus*, *Trochus*, *Triton*, *Nassa*, and *Bulla*.

The *species*, however, do not agree with those of the tertiary strata, and are associated with cephalopoda of those extinct families before mentioned as characteristic of the cretaceous, and foreign to the tertiary epoch; as, for example, the *Ammonite*, *Belemnite*, and *Baculite*: two species, the *Belemnites mucronatus* (Fig. 175.), and the *Baculites Faujasii* (Fig. 176.), being common to the Faxoe beds and the white chalk.

From these facts, we may conclude that the

Faxoe limestone was formed in the cretaceous sea, in a spot favourable for the multiplication of stony corals and univalve shells; and as some small portions of the rock consist of white earthy chalk, this latter substance must have been produced simultaneously, and some of it may have been washed away, in the form of mud, from the coral reef of Faxoe, and dispersed over the deeper parts of the same ocean, just as the white mud, swept out of the lagoons of the Bermudas or coral islets of the Pacific, must form deposits of white chalk, covering much wider spaces than those occupied by the reefs.

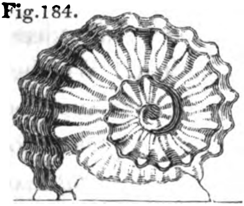
The same remarks apply to a rock, which reposes on the Upper Chalk with flints, at St. Peter's Mount, Maestricht, and at Ciply, near Mons. It is a soft yellowish stone, not very unlike chalk, and "includes siliceous masses, which are much more rare than those of the chalk, of greater bulk, and not composed of black flint, but of chert and calcedony."* Like the Faxoe stone, it is characterized by a peculiar assemblage of organic remains, which are specifically distinct from those of the tertiary period, but many of them common to the white chalk.

As these Maestricht beds have been thought to be intermediate in character between the secondary and tertiary formations, it may be proper to

* Fitton, Geol. Proceedings, 1830.

mention, as opposed to this opinion, that the *Ammonite* (Fig. 184.), *Baculite*, *Hamite*, and *Hippurite*, have been found in the Maestricht limestone, genera which have not yet been detected in strata newer than the chalk. In the same formation, also, large turtles have been found, and a gigantic reptile, the *Mosasaurus*, or fossil Monitor, some of the vertebræ of which appear also in the English chalk.* The osteological characters of this oviparous quadruped prove it to have been intermediate between the living Monitors and Iguanas; and, from the size of the head, vertebræ, and other bones, it is supposed to have been twenty-four feet in length.

Fig. 184.



Ammonites Rhotomagensis.
Maestricht; found by Count Munster.

The existence of such turtles and saurians seems to imply some neighbouring land, on the sandy shores of which these creatures may have laid their eggs. But a few small islets in mid-ocean, like Ascension, so much frequented by turtles, may perhaps have afforded the required retreat to these cretaceous reptiles.

Origin of the flint in chalk.—It is difficult to give a satisfactory explanation of the origin of the

* See Mantell's Geol. of S. E. of England.

flint in chalk, whether it occurs in isolated nodules or continuous layers. It seems that there was originally siliceous as well as calcareous earth in the muddy bottom of the cretaceous sea, at least when the upper chalk was deposited. Whether both these earths could have been alike supplied by the decay of organic bodies may be matter of speculation; but what was said of the origin of Tripoli (see p. 53.) shows how microscopic infusoria can give rise to dense masses of pure flint. The skeletons of many living sponges consist of needles or spicula of flint, and these are found very abundantly in the flints of the chalk. There are also other living zoophytes, which have the power of secreting siliceous matters from the waters of the sea, just as mollusca secrete calcareous particles.

From whatever source the mud derived its silex, we may attribute the parallel disposition of the flinty layers to successive deposition. The distances between the layers, says Dr. Buckland, must have been regulated by the intervals of precipitation, each new mass forming at the bottom of the ocean a bed of pulpy fluid, which did not penetrate the preceding bed on which it rested, because the consolidation of this last was so far advanced as to prevent such intermixture.* Never-

* Geol. Trans., First Series, vol. iv. p. 420.

theless the separation of the flint into layers, so distinct from the chalk, is a singular phenomenon, and not yet accounted for. Perhaps, as the specific gravity of the siliceous exceeds that of the calcareous particles, the heavier flint may have sunk to the bottom of each stratum of soft mud?

Geographical extent of White Chalk. — The area over which the white chalk preserves a nearly homogeneous aspect is so great that geologists have often despaired of finding any analogous deposits of recent date; for chalk is met with in a north-west and south-east direction, from the north of Ireland to the Crimea, a distance of about 1140 geographical miles, and in an opposite direction it extends from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles. But we must not conclude that it was ever spread out uniformly over the whole of this vast space, but merely that there were patches of it, of various sizes, throughout this area. Now, if we turn to those regions of the Pacific over which coral reefs are scattered, we find some archipelagoes of lagoon islands, such as that of the Dangerous Archipelago for instance, and that of Radack, with some adjoining groups, which are from 1100 to 1200 miles in length, and 300 or 400 miles broad; and the space to which Flinders proposed to give the name of the Corallian sea is still larger; for it is bounded on the

east by the Australian barrier, on the west by New Caledonia, and on the north by the reefs of Louisiade. Although the islands in these spaees may be thinly sown, the mud of the decomposing zoophytes may be scattered far and wide by oceanic currents.

Green-sand formation. — The lower part of the Cretaceous group in England, is divisible, as we have already seen, into Upper Green-sand, Gault, and Lower Green-sand. The green grains have been found, by analysis, to consist chiefly of silicate of iron, and they agree in composition with chlorite. The inferior white marly chalk becomes more and more charged with these grains until it passes into the upper green sand, a formation of sand and sandy marl, frequently mixed with chert, and this again passes downwards into the clay and marl, provincially called Gault. Both of these subdivisions, although often diminishing in volume to a thickness of two or three yards, form distinct and continuous bands of sand and clay between the chalk and lower green-sand throughout considerable tracts in England, France, and Belgium; and each preserves throughout this space certain mineral peculiarities and characteristic fossils.

The lower green-sand below the gault is formed partly of green and partly of ferruginous sand and sandstone, with some limestone. These rocks

succeed each other in the following descending order in Kent: —

No. 1.	Sand, white, yellowish, or ferruginous, with concretions of limestone and chert	-	70 feet.
2.	Sand with green matter	-	70 to 100 feet.
3.	Calcareous stone, called Kentish rag	-	60 to 80 feet.*

The fossils of the green-sand are marine, and some of them, like the *Pecten quinquecostatus* (Fig. 186.), range through all the members of the

FOSSILS OF THE GREEN-SAND FORMATION.

Fig. 185.

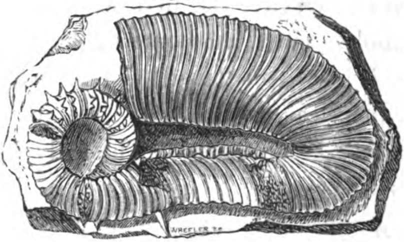
a b

a. Terebratula lyra. } Upper green-sand.
b. Same, seen in profile. } France.

Fig. 186.

Pecten 5 costatus.
Upper and lower green-sand.

Fig. 187.



Hamites spiniger (Fitton); near Folkstone.† Gault.

series. Several forms of cephalopoda, such as the *Hamite* (Fig. 187), *Scaphite*, and others, distin-

* Fitton, Geol. Trans., Second Series, vol. iv. p. 319.
† Ibid. pl. 12.

guish the Green-sand formation in England from the White Chalk.

Origin of the Green-sand formation.—Unlike the white chalk, this deposit consists of a succession of ordinary beds of sand, clay, marl, and impure limestone, the materials of which might result from the wearing down of pre-existing rocks. The nature of these derivative rocks we learn, from finding in the green-sand pebbles of quartz, quartzose sandstone, jasper, and flinty slate, together with grains of chlorite and mica.* But we naturally inquire, how it could happen that, throughout a large submarine area, there should be formed, first, a set of mechanical strata, such as the green-sand, and then over the same space a pure zoophytic and shelly limestone, such as the white chalk. Certain causes, which, during the first period, gave rise to deposits of mud, sand, and pebbles, must subsequently have ceased to act; for it is evident that no similar sediment disturbed the clear waters of the sea in which the white chalk accumulated. The only hypothesis which seems capable of explaining such changes is the gradual submergence of land which had been previously exposed to aqueous denudation. This operation may have gone on with such slowness as to allow time for considerable fluctuations

* Fitton, Geol. Trans., Second Series, vol. iv. p. 116.

in the state of the organic world, so that different sets of strata, beginning with the Lower Green-sand, and ending with the Upper White Chalk, may each contain some peculiar remains of animals which lived successively in the sea; while some species may have continued to exist throughout the whole period, and are therefore common to all these formations.

It will be seen in the next chapter, when we treat of the strata called the Wealden, that such a general subsidence of land as is here supposed to explain the manner in which the Chalk succeeds the Green-sand, may be inferred from other independent proofs to have taken place throughout large areas.

It cannot, however, be assumed, that all the green-sand in Europe had ceased to be deposited before any chalk began to accumulate. Such, indeed, was the order of events in parts of England, France, Belgium, and Denmark; but if we compare different countries, and some of these not far distant from each other, we find reason to believe that sand and clay continued to be thrown down in one place, while pure chalk was forming in another. In Westphalia, for example, strata containing the same fossils as the white chalk of England, consist of sand and marl with green grains like the upper green-sand. Similar facts

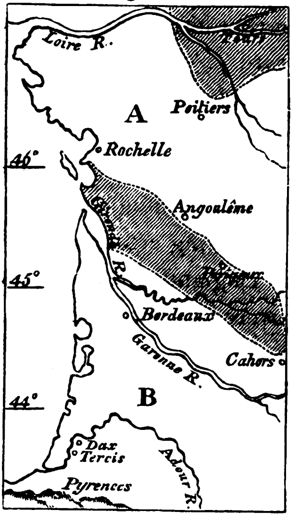
have been observed in Hungary, in the Carpathian mountain chain. Such variations would occur if the supposed sinking down of land did not take place simultaneously everywhere; and for this reason the minor subdivisions of the Cretaceous group, however persistent and uniform in their mineral characters in some regions, vary rapidly, and change entirely in other directions.

Difference between the chalk of the north and south of Europe.—By the aid of the three tests of relative age, namely, superposition, mineral character, and fossils, the geologist has been enabled to refer to the same Cretaceous period certain rocks in the north and south of Europe, which differ greatly, both in their fossil contents and in their mineral composition and structure.

If we attempt to trace the cretaceous deposits from England and France to the countries bordering the Mediterranean, we perceive, in the first place, that the chalk and green-sand in the neighbourhood of London and Paris form one great continuous mass, the strait of Dover being a trifling interruption, a mere valley with chalk cliffs on both sides. We then observe that the main body of the chalk which surrounds Paris stretches from Tours to near Poitiers (see the annexed map, Fig. 188., in which the shaded part represents chalk).

Between Poitiers and La Rochelle, the space marked A on the map separates two regions of chalk. This space is occupied by the Oolite and certain other formations older than the Chalk, and has been supposed by M. E. de Beaumont to have formed an island in the cretaceous sea. South of this space we again meet with a formation which we at once recognize by its mineral character to be chalk, although there are some places where the rock becomes oolitic. The fossils are, upon the whole, very similar; especially certain species of the genera *Spatangus*, *Ananchytes*, *Cidarites*, *Nucula*, *Ostrea*, *Gryphæa* (*Exogyra*), *Pecten*, *Plagiostoma* (*Lima*), *Trigonia*, *Catillus*, and *Terebratula*.* But *Ammonites*, as M. d'Archiac observes, of which so many species are met with in the chalk of the north of France, are scarcely ever found in the southern region; while the genera *Hamite*, *Tur-*

Fig. 188.



* Archiac, sur la Form. Crétacée du S. O. de la France, Mém. de la Soc. Géol. de France, tom. ii.

rilite and *Scaphite*, and perhaps *Belemnite*, are entirely wanting.

On the other hand, certain forms are common in the south which are rare or wholly unknown in the north of France. Among these may be mentioned many *Hippurites*, *Sphærulites*, and other members of that great family of mollusca called *Rudistes* by Lamarck, to which nothing analogous has been discovered in the living creation. Although very uncommon in England, one species of this family has been discovered in our chalk.

Fig. 189.

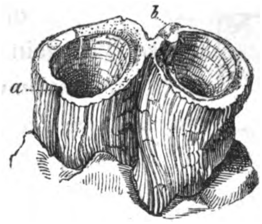


Fig. 190.

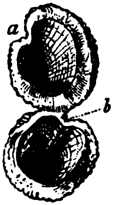


Fig. 191.

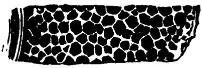


Fig. 192.

Hippurites Mortoni, Mantell. Houghton, Sussex.
Diameter one seventh of nat. size.

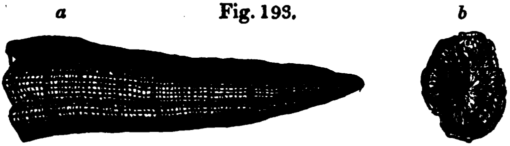
Fig. 189. Two individuals deprived of their opercula, adhering together.
190. Same seen from above.
191. Transverse section of part of the wall of the shell, magnified to show the structure.
192. Vertical section of the same.

On the side where the shell is thinnest, there is one external furrow and corresponding internal ridge, *a. b.* Figs. 189, 190.;

but they are usually less prominent than in these figures. This species has been referred to *Hippurites*, but does not, I believe, fully agree in character with that genus. I have never seen the opercular piece, or *valve*, as it is called by those conchologists who regard the *Rudistes* as bivalve mollusca. The specimen above figured was discovered by Mr. F. Dixon.

But this family, which is so feebly represented in England and the north of France, becomes quite characteristic of rocks of the Cretaceous era in the south of France, Spain, Greece, and other countries bordering the Mediterranean.

Fig. 193.

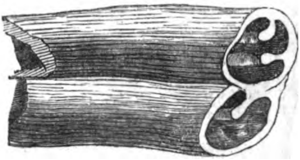


a. Hippurites, Lamk.
b. Opercular valve of *H. radiosa.* } Lower chalk, South of France.

Fig. 194.

Sphærulites agariciformis.

Fig. 195.



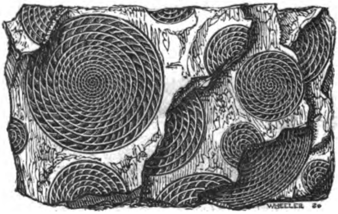
Hippurites organisans, Desm. Pyrenees.

Between the region of chalk last mentioned in which Perigueux is situated, and the Pyrenees, the space B intervenes (see Map).

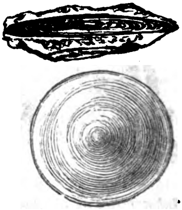
Here the tertiary strata cover, and for the most part conceal, the cretaceous rocks, except in some

spots where they have been laid open by the denudation of the newer formations. In these places they are seen still preserving the form of a white chalky rock, which is charged in part with grains of green sand. Even as far south as Tercis, on the Adour, near Dax, cretaceous rocks retain this character where I examined them in 1828, and where M. Grateloup has found in them *Ananchytes ovata* (Fig. 178.), and other fossils of the English chalk, together with *Hippurites*. When we arrive at Bayonne and the Pyrenees, the Cretaceous formation, although still exhibiting some of the same mineralogical peculiarities, is nevertheless greatly changed. Its calcareous division consists for the most part of compact crystalline marble, often full of Nummulites (see Fig. 196.), and those

Fig. 196.



b



a

Nummulite limestone; Peyrehorade, Pyrenees.

a. External surface of one of the nummulites, of which longitudinal sections are seen in the limestone.

b. Transverse section of same.

portions which may be imagined to represent the green-sand, are composed of shales, grits, and mi-

caceous sandstone, containing impressions of marine plants, together with lignite and coal. There are also beds of red sandstone and conglomerate belonging to the same group. These rocks ascend gradually into the highest parts of the Pyrenees, and cross over into Spain, where the Cretaceous system assumes a character still more unlike that of northern Europe.

Here,* as on the north side of the Pyrenees, the most conspicuous fossils are *Hippurites*, *Sphærulites*, and *Nummulites*. The last-named fossil, so called from its resemblance to a piece of money, is a genus of foraminifera very abundant in the tertiary strata of northern Europe; but is rare in the cretaceous system except in the south of Europe.

So many species and genera of shells now wanting in our northern seas, are frequent in the Mediterranean, that we need not be surprised, when following from north to south the deposits of the old cretaceous sea, at finding similar modifications in organic forms.

The cretaceous rocks in the Alps, Italy, Greece, and Asia Minor, are distinct in like manner from the type of that formation in the north of Europe; yet their age in most of these countries can be clearly ascertained, partly by following them continuously from the north in the manner above de-

scribed; and partly by their position below the tertiary, and above the oolitic strata.

We learn from the researches of M. M. Boblaye and Virlet, that the cretaceous system in the Morea, is composed of compact and lithographic limestones of great thickness; also of granular limestones, with jasper; and in some districts, as in Messenia, a puddingstone with a siliceous cement, more than 1600 feet in thickness, belongs to the same group.*

It is evident, observe these geologists, from the great range of the hippurite and nummulite limestone, that the South of Europe was occupied at the Cretaceous period by an immense sea, which extended from the Atlantic Ocean into Asia, and comprehended the southernmost part of France, together with Spain, Sicily, part of Italy, and the Austrian Alps, Dalmatia, Albania, a portion of Syria, the isles of the Ægean, coasts of Thrace, and the Troad.

In proportion, therefore, as we enlarge the sphere of our researches, we may find in the strata of one era, the mineralogical counterparts of the rocks, which, in a single country like England, may characterize successive periods. Thus, the grits, sandstone, and shale with coal, of the Pyrenees have actually been mistaken by skilful

* Bull. de la Soc. Géol. de France, tom. iii. p. 149.

miners for the ancient Carboniferous group of England and France. In like manner, the Cretaceous red marl and salt of northern Spain have been regarded as the same as our New Red and saliferous sandstone; and the lithographic limestone of the Morea might be confounded with the Oolite of Solenhofen in Germany.

The beginner, perhaps, on hearing these facts, may object to the term cretaceous, as applied to the rocks of the southern region in which there is no chalk. But the term green-sand would have been equally inappropriate as a general name for this group; and that of hippurite and nummulite limestone, however well suited to the Mediterranean region, would be inapplicable to the chalk of the north. Scarcely any designation would remain unexceptionable as we enlarge the bounds of our knowledge, and we must therefore be content to retain many ancient names, as simply expressing the mineral or palæontological characters of rocks *in the country where they were first studied.*

CHAPTER XVIII.

WEALDEN GROUP.

The Wealden, including the Weald clay, Hastings sand, and Purbeck beds — Intercalated between two marine formations — Fossil shells freshwater, with a few marine — Cypris — Fish — Reptiles — Birds — Plants — Section showing passage of Wealden beneath chalk — Junction of Wealden and Oolite — Dirt-bed — Theory of gradual subsidence — Proofs that the Wealden strata, notwithstanding their thickness, may have been formed in shallow water — Geographical extent of Wealden—Bray near Beauvais—Relation of the Wealden to the Lower Green Sand and Oolite.

Beneath the cretaceous rocks in the S. E. of England, a freshwater formation is found called the Wealden, which, although it occupies a small area in Europe, as compared to the chalk, is nevertheless of great interest, as being intercalated between two marine formations. It is composed of three minor groups, of which the aggregate thickness in some places cannot be less than 800 feet.* These subdivisions are,

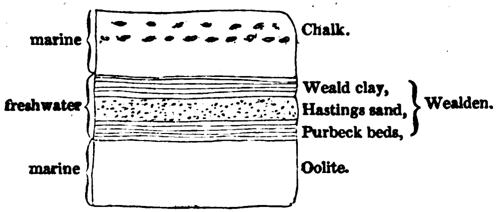
		Thickness.
1st.	Weald Clay, sometimes including thin beds of sand and shelly limestone -	140 to 280 ft.
2d.	Hastings sand, in which occurs some clays and calcareous grits;—between -	400 and 500 ft.
3d.	Purbeck beds, consisting of various kinds of limestones and marls - -	about 250 ft.

* Dr. Fitton, Geol. Trans. vol. iv. p. 320. Second Series.

To all these subdivisions, the common name of the Wealden has been given, because they may be best studied in part of Kent, Surrey, and Sussex, called the Weald.

We have seen that the fossils of the Chalk and Green-Sands which repose upon the Wealden are all marine, and the species numerous; and the same remark applies to the Portland stone and other members of the Oolitic series which lie immediately beneath (see Fig. 197.). But in the

Fig. 197.



Position of the Wealden between two marine formations.

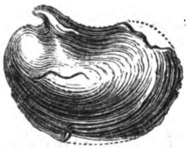
Wealden itself, although the fossils are abundant as to quantity, the number of different species is comparatively small, and by far the greater part of them show that they were deposited in a fresh-water lake, or estuary communicating with the sea.*

Fossils of the Wealden. — The shells of this formation are almost exclusively of fluviatile or

* Fitton, Geol. Trans. vol. iv. p. 104. Second Series.

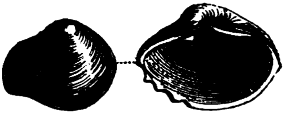
lacustrine genera, such as *Melanopsis*, *Paludina*, *Neritina*, *Cyclas*, *Unio*, and others. The individuals are sometimes in such profusion, that the surface of each thin layer of marl or clay is covered with the valves of *Cyclas*, and whole beds of limestone are almost entirely composed of *Paludinæ*. Intermixed with these freshwater shells, there are a few which seem to mark the occasional presence of salt water, as for example, a species of *Bulla*, together with an Oyster, and the *Exogyra*, a genus of unimuscular bivalves allied to the oyster (see Fig. 198.). The conclusion to be drawn from the presence of a *Corbula* (see Fig. 199.) and

Fig. 198.



Exogyra bulla, Fitton.

Fig. 199.



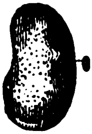
Corbula, alata, Fitton.
Magnified.

Mytilus is more doubtful; for although these genera are for the most part marine, still there is a *Mytilus* living in the Danube, and one species of *Corbula* inhabits the river La Plata, in South America, as well as the adjoining sea, while another is common to the Caspian, and the rivers

Don and Wolga. But admitting all these to have been marine, they by no means outweigh the evidence, both of a positive and negative kind, derived from shells in favour of the freshwater origin of the Wealden. In no part of this deposit do we meet with ammonites, belemnites, terebratulæ, corals, sea-urchins, or other testacea and zoophytes so characteristic of the chalk above, or the oolite below the Wealden.

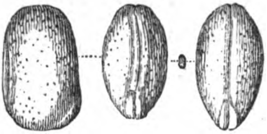
Shells of the *Cypris*, an animal allied to the Crustacea, and before mentioned (p. 67.) as

Fig. 200.



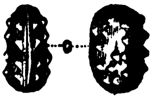
Cypris spinigera, Fitton.

Fig. 201.



Cypris Valdensis, Fitton. (*C. faba*, Min. Con. 485.)

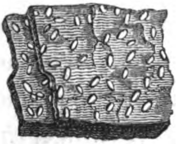
Fig. 202.



Cypris tuberculata, Fitton.

abounding in lakes and ponds, are also plentifully scattered through the clays of the Wealden, sometimes producing, like plates of mica, a thin lamination (see Fig. 203.). Similar cypriferous marls are found in the lacustrine tertiary beds of Auvergne, and in recent deposits of shell-marl.

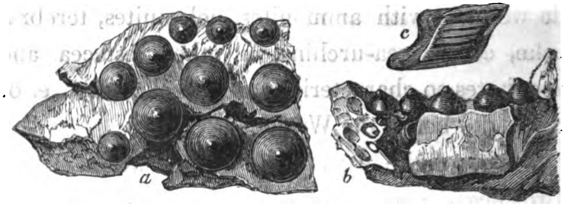
Fig. 203.



The fishes of the Wealden belong partly to the

genera *Pycnodus* and *Hybodus* (see Figures in Chapters 21 and 22.), forms common to the Wealden and Oolite; but the teeth and scales of a species of *Lepidotus* are most widely diffused (see

Fig. 204.



Lepidotus Mantelli, Agass. Wealden.
a. palate and teeth. *b.* side view of teeth. *c.* scale.

Fig. 204.). The general form of these fish was that of the carp tribe, although perfectly distinct in anatomical character, and more allied to the pike. The whole body was covered with large rhomboidal scales, very thick, and having the exposed part covered with enamel. Most of the species of this genus are supposed to have been either river fish, or inhabitants of the coasts, having not sufficient powers of swimming to advance into the deep sea.

Among the remains of vertebrata, those of reptiles form the most remarkable feature. Some of them belong to tortoises, such as the *Trionyx* and *Emys*, genera now occurring in freshwater in tropical regions. Of Saurian lizards there are at least five genera; the Crocodile, Plesiosaur, Megalosaur, Iguanodon, and Hylæosaur. The Iguan-

odon, of which the remains were first discovered by Mr. Mantell, was an herbivorous reptile, and was regarded by Cuvier as more extraordinary than any with which he was acquainted; for the teeth, though bearing a great analogy to the modern Iguanas which now frequent the tropical woods of America and the West Indies, exhibit many striking and important differences (see Fig. 206.). It appears that they have been worn by mastication; whereas the existing herbivorous reptiles clip and gnaw off the vegetable productions on which they feed, but do not chew them. Their teeth, when worn, present an ap-

Teeth of Iguanodon.

Fig. 205.

Crown of tooth in adult, worn down.
Mantell.

Fig. 206.

Pointed tooth of a young animal.
Mantell.

pearance of having been chipped off, and never, like the fossil teeth of the Iguanodon, have a flat ground surface (see Fig. 205.), resembling the grinders of herbivorous mammalia. Mr. Mantell computes that the teeth and bones of this animal

which have passed under his examination during the last twenty years, must have belonged to no less than seventy-one distinct individuals; varying in age and magnitude from the reptile just burst from the egg, to one of which the femur measured twenty-four inches in circumference. Yet notwithstanding that the teeth were more numerous than any other bones, it is remarkable that it was not till the relics of all these individuals had been found, that a solitary example of part of a jaw-bone was obtained.

The bones of birds of the order *Grallæ* or waders have been discovered by Mr. Mantell in the Wealden, and appear to be the oldest well-authenticated examples of fossils of this class hitherto found in Great Britain.* But no portion of the skeleton of a mammiferous quadruped has yet been met with.

The vegetable remains, which are numerous,

Fig. 207.

Cone from the Isle of Purbeck, resembling the Dammara of the Moluccas. Fitton.

Fig. 208.

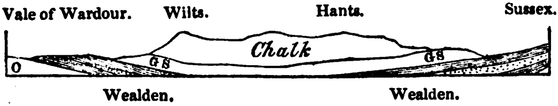
Sphenopteris gracilis (Fitton), *from near Tunbridge Wells.*
a. portion of the same magnified.

* Mantell, Proceedings Geol. Soc. vol. ii. p. 203.

exhibit many characters of a tropical flora, some being allied to the living genera *Cycas* and *Zamia* (see Fig. 211.), others to large *Equiseta*. There are also *Coniferæ* allied to *Araucaria*, and other genera of warm climates (see Fig. 207.), besides numerous ferns (see Fig. 208.).

Passage of Wealden beneath Chalk. — It has been already seen that the chalk and green sand have an aggregate thickness of 1000 or sometimes 1500 feet. It is therefore a wonderful fact that after penetrating these rocks, we come down upon a subjacent *freshwater* formation from 800 to 1000 feet in thickness. The order of superposition is clear, for we see the Weald Clay passing beneath the Green-Sand in various parts of Surrey, Kent, and Sussex; and if we proceed from Sussex westward to the Vale of Wardour, we there again observe the same formation occupying the same relative position, and resting on the Oolite (see Fig. 209.). Or if we pass from the base of the

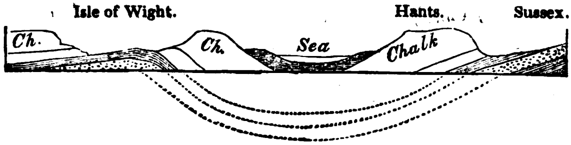
Fig. 209.



south downs in Sussex, and cross to the Isle of Wight, we there again meet with the same series reappearing beneath the Green-Sand, and we cannot doubt that the beds are prolonged sub-

terraneously, as indicated by the dotted lines in Fig. 210.

Fig. 210.



It has been already suggested that, during the accumulation of the Green-Sand, there was a gradual sinking down and submersion of land, by which the wide open sea of the Chalk was produced. But the position of the Wealden points still more forcibly to such a conclusion, and especially the appearances exhibited at the point of junction of the Wealden, and the Oolitic formation on which it rests. First, in regard to its junction with the superincumbent Lower Green-Sand, the beds of this last, says Dr. Fitton, repose in the south-east of England, conformably upon those of the subjacent Weald Clay. There is no indication of disturbance: "To all appearance the change from the deposition of the freshwater remains to that of the marine shells, may have been effected simply by a tranquil submersion of the land to a greater depth beneath the surface of the waters." *

Portland dirt-bed and proofs of subsidence.—But

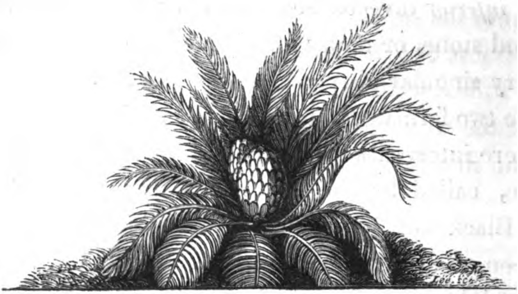
* Geol. of Hastings, p. 28.

when we examine the contact of the Purbeck beds, or *inferior* division of the Wealden, with the Portland stone, or upper member of the Oolite, some very singular phenomena are observed. Between the two formations, the marine and the freshwater, there intervenes in Portland a layer of dark matter, called by the quarrymen the "Dirt," or "Black dirt," which appears evidently to have been an ancient vegetable soil. It is from twelve to eighteen inches thick, is of a dark brown or black colour, and contains a large proportion of earthy lignite. Through it are dispersed rounded fragments of stone, from three to nine inches in diameter, in such numbers that it almost deserves the name of gravel. Many silicified trunks of coniferous trees, and the remains of plants allied to the *Zamia* and *Cycas* are buried in this dirt-bed (see figure of living *Zamia*).

These plants must have become fossil on the spots where they grew. The stumps of the trees stand erect for a height of from one to three feet, and even in one instance to six feet, with their roots attached to the soil at about the same distances from one another as the trees in a modern forest.* The carbonaceous matter is most abun-

* Mr. Webster first noticed the erect position of the trees and described the Dirt-bed. The account here given is drawn from Dr. Buckland and Mr. De la Beche, Geol. Trans., Second Series, vol. iv. p. 1.; Mantell, Geol. of S. E. of England, p. 336.; and Dr. Fitton, Geol. Trans., Second Series, vol. iv. p. 220.

Fig. 211.



Zamia spiralis; Southern Australia. *

dant immediately around the stumps, and round the remains of fossil *Cycadeæ.* †

Besides the upright stumps above mentioned, the dirt-bed contains the stems of silicified trees laid prostrate. These are partly sunk into the black earth, and partly enveloped by a calcareo-siliceous slate which covers the dirt-bed. The fragments of the prostrate trees are rarely more than three or four feet in length; but by joining many of them together, trunks have been restored having a length from the root to the branches of from 20 to 23 feet, the stems being undivided for 17 or 20 feet, and then forked. The diameter of these near the roots is about one foot. ‡ Root-shaped cavities were observed by Professor

* See Flinder's Voyage.
† Fitton, Geol. Trans., Second Series, vol. iv. pp. 220, 221.
‡ Fitton, ibid.

Henslow to descend from the bottom of the dirt-bed into the subjacent Portland stone, so that the uppermost beds of the Portland limestone, though now solid, were in a soft and penetrable state when the trees grew. *

The thin layers of calcareous slate (Fig. 212.),

Fig. 212.

Section in Isle of Portland, Dorset. (Buckland and De la Beche.)

were evidently deposited tranquilly, and would have been horizontal but for the protrusion of the stumps of the trees, around the top of each of which they form hemispherical concretions.

The dirt-bed is by no means confined to the island of Portland, but is seen in the same relative position in a cliff east of Lulworth Cove, in Dorsetshire, where, as the strata have been disturbed, and are now inclined at an angle of 45°, the stumps of the trees are also inclined at the same angle in an opposite direction — a beautiful illustration of a change in the position of beds

* Buckland and De la Beche, Geol. Trans., Second Series, vol. iv. p. 16.

originally horizontal (see Fig. 213.). Traces of the dirt-bed have also been observed by Dr. Buckland, about two miles north of Thame, in Ox-

Fig. 213.

Section in cliff east of Lulworth Cove. (Buckland and De la Beche.)

fordshire; and by Dr. Fitton, in the cliffs of the Boulonnois, on the French coast; but, as might be expected, this freshwater deposit is of limited extent when compared to most marine formations.

From the facts above described, we may infer, first, that the superior beds of the Oolite, which are full of marine shells, became dry land, and covered by a forest, throughout a portion of the space now occupied by the south of England, the climate being such as to admit the growth of the *zamia* and *cycas*. 2dly. This land at length sank down and was submerged with its forests beneath a body of freshwater, from which sediment enveloping fluviatile shells was deposited. 3dly. "The regular and uniform preservation of this thin bed of black earth over a distance of many miles,

shows that the change from dry land to the state of a freshwater lake or estuary, was not accompanied by any violent denudation, or rush of water, since the loose black earth, together with the trees which lay prostrate on its surface, must inevitably have been swept away had any such violent catastrophe then taken place." *

The dirt-bed has been described above in its most simple form, but in some sections the appearances are more complicated. The forest of the dirt-bed was not everywhere the first vegetation which grew in this region. Two other beds of carbonaceous clay, one of them containing *Cycadeæ* in an upright position have been found below it †, which implies other oscillations in the level of the same ground, and its alternate occupation by land and water more than once. There must have been, first, the sea in which the corals and shells of the Oolite grew; then, land, which supported a vegetable soil with *Cycadeæ;* then, a lake or estuary, in which freshwater strata were deposited; then, again, land, on which other *Cycadeæ* and a forest of dicotyledonous trees flourished: then, a second submergence under freshwater, in which the Wealden strata were gradually formed; and,

* Buckland and De la Beche, Geol. Trans., Second Series, vol. iv. p. 16.

† Fitton, Geol. Trans., Second Series, vol. iv. p. 223.

finally, in the Cretaceous period, a return over the same space of the ocean.

To imagine such a series of events will appear extravagant and visionary to some who are not aware that similar changes occur in the ordinary course of nature; and that large areas near the sea are now subject to be laid dry, and then submerged, after remaining for years covered with houses and trees.*

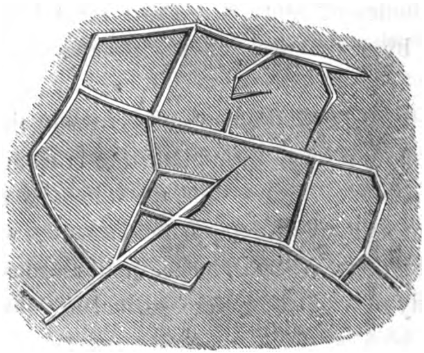
In some of these modern revolutions, such as have been witnessed in the delta of the Indus, in Cutch, we have instances of land being permanently laid under the waters, both of the river and the sea, without the soil and its shrubs being swept away; but such preservation of an ancient soil must be a rare exception to the general rule, for it would be destroyed by denuding waves and currents, unless the land sank suddenly down to a great depth, or unless its form was such as to exclude the free ingress of the sea.

Notwithstanding the enormous thickness of the Wealden, exceeding in some places perhaps 1000 feet, there are many grounds for believing that the whole of it was a deposit in water of a moderate depth, and often extremely shallow. This idea may seem startling at first, yet such would be

* For an account of recent movements of land attended by such consequences, see Principles of Geology, Index, "Cutch," "Sindree," &c.

the natural consequence of a gradual and continuous sinking of the ground in an estuary or bay, into which a great river discharged its turbid waters. By each foot of subsidence, the fundamental rock, such as the Portland Oolite, would be depressed one foot farther from the surface of the ocean; but the bay would not be deepened, if new strata of mud and sand should raise the bottom one foot. On the contrary, such sand and mud might be frequently laid dry at low water, or overgrown for a season by a vegetation proper to marshes. At different heights in the Hastings Sand, in the middle of the Wealden, we find again and again slabs of sandstone with a strong ripple-mark, and between these slabs beds of clay many yards thick. In some places, as at Stammerham, near Horsham,

Fig. 214.



Underside of slab of sandstone about one yard in diameter; Stammerham, Sussex.

there are indications of this clay having been ex-

posed so as to dry and crack before the next layer was thrown down upon it. The open cracks in the clay have served as moulds, of which casts have been taken in relief, and which are, therefore, seen on the lower surface of the sandstone * (see Fig. 214.).

Near the same place a reddish sandstone occurs in which are innumerable traces of a fossil vegetable, apparently *Sphenopteris*, the stems and branches of which are disposed as if the plants were standing erect on the spot where they originally grew, the sand having been gently deposited upon and around them; and similar appearances have been remarked in other places in this formation.† In the same division also of the Wealden, at Cuckfield, is a bed of gravel or conglomerate, consisting of water-worn pebbles of quartz and jasper, with rolled bones of reptiles. These must have been drifted by a current, probably in water of no great depth.

The occasional presence of oysters in the Purbeck limestone, and throughout the Hastings sand and Weald clay, proves that the waters of the sea sometimes found access into the estuary ‡, whether in consequence of subsidence, or in seasons when the body of freshwater was lessened in volume.

* Observed by Mr. Mantell and myself in 1831.

† Mantell, Geol. of S.E. of England, p. 244.

‡ Fitton, Geol. Trans., 2d Ser., vol. iv. p. 321.

Geographical extent.—The Wealden strata have been traced about 200 English miles from west to east, from Lulworth Cove to near Boulogne, in France, and about 220 miles from north-west to south-east, from Whitchurch, in Buckinghamshire, to Beauvais, in France. If the formation be continuous throughout this space, which is very doubtful, it does not follow that the whole was contemporaneous; because in all likelihood the physical geography of the region underwent frequent change throughout the whole period, and the estuary may have altered its form, and even shifted its place. Yet some modern deltas are of vast size, as for example that of the newly-discovered Quorra, or Niger, in Africa, which stretches into the interior for more than 170 miles, and occupies, it is supposed, a space of more than 300 miles along the coast; thus forming a surface of more than 25,000 square miles, or equal to about one half of England.*

I have stated that the Wealden has been observed near Beauvais, in France; and the locality is marked in the section at p. 387. It is called "the country of Bray;" and resembles in structure the English Weald between the North and South Downs. In a similar manner the Green Sand crops out from beneath the Chalk, and freshwater

* Fitton, Geol. of Hastings, p. 58.; who cites Lander's Travels.

strata from beneath the Green Sand. One member of the series, a fine whitish sand, contains impressions of ferns, considered by M. Adolphe Brongniart as identical with *Lonchopteris Mantelli*, a plant found frequently in the Wealden. I examined part of the valley of Bray in company with M. Graves, in 1833, and I observed that the sand last mentioned, with its vegetable remains, was intercalated between two sets of marine strata, containing *trigoniæ*, and referred by French geologists to the lower Green Sand. In the same country of Bray, and associated with the same formation, is a limestone resembling the Purbeck marble, and containing a *Paludina* which seems specifically identical with that of Purbeck.

If it be asked where the continent was placed from the ruins of which the Wealden strata were derived, and by the drainage of which a great river was fed, we are half tempted to speculate on the former existence of the Atlantis of Plato. The story of the submergence of an ancient continent, however fabulous in history, may be true as a geological event. Its disappearance may have been gradual; and we need not suppose that the rate of subsidence was hastened at the period when the displacement of a great body of fresh water by the Cretaceous sea took place. Suppose the mean height of the land drained by the river of the Wealden estuary to have been no more than 800

or 1000 feet; in that case, all except the tops of the mountains would be covered as soon as the fundamental Oolite and the dirt-bed were sunk down about 1000 feet below the level which they occupied when the forest before-mentioned was growing. Towards the close of the period of this subsidence, both the sea would encroach and the river diminish in volume more rapidly; yet in such a manner, that we may easily conceive the sediment at first washed into the advancing sea to have resembled that previously deposited by the river in the estuary. In fact, the upper beds of the Wealden, and the inferior strata of the Lower Green Sand, are not only conformable, but of similar mineral composition.

It is also a remarkable fact, that the same *Iguanodon Mantelli* which is so conspicuous a fossil in the Wealden, has recently been discovered near Maidstone, in the overlying Kentish rag, or marine limestone of the Lower Green Sand. Hence we may infer that some of the saurians which inhabited the country of the great river, continued to live when part of the country had become submerged beneath the sea. Thus, in our own times, we may suppose the bones of large alligators to be frequently entombed in recent freshwater strata in the delta of the Ganges. But if part of that delta should sink down so as to be covered by the sea, marine formations might begin to accumulate

in the same space where freshwater beds had previously been formed; and yet the Ganges might still pour down its turbid waters in the same direction, and carry the carcasses of the same species of alligator to the sea, in which case their bones might be included in marine as well as in subjacent freshwater strata.

Age of the Wealden. — Some geologists have classed the Wealden as a member of the Cretaceous group, while others have considered it as more nearly connected with the antecedent Oolitic deposits; nor is it easy to decide which opinion is preferable, because the organic remains of the Cretaceous and Oolitic groups are marine, while those of the interposed Wealden are almost all freshwater. The testacea and plants of the latter appear as yet to be specifically distinct from those of any other formation; but if we examine the reptiles, it appears that the *Megalòsaurus Bucklandi* is common to the Oolite and Wealden, the teeth and bones of this great saurian occurring both in the limestone of Stonesfield and in the Hastings sand.

There are also some *generic* forms, both of reptiles and fish, common to the Oolite and Wealden, and not yet discovered in the Chalk. Vertebræ, for example, of the *Plesiosaurus* are not confined to the Oolite and Lias, but have been also found in the Wealden; and the *Lepidotus*, a genus of fish

very characteristic of the Wealden, is unknown in the Cretaceous group, while it is abundant in the Oolitic series.

On the other hand, the same species of Iguanodon has been already mentioned as decidedly common to the Wealden and Green-Sand.

In Scotland, and in different parts of the Continent, marine deposits have been found which are supposed to have been coeval with the Wealden, and which are intermediate in fossil characters as in position between the Cretaceous and Oolitic systems.* They may have been contemporaneous deltas of other rivers flowing from the same ancient continent.

Absence of mammalia. — Among the numerous fossils of the Wealden, no remains of mammalia have been hitherto detected; whereas we should naturally expect, on examining the deposits recently formed at the mouths of the Quorra, Indus, or Ganges, to find, not only the bones of birds and of amphibious and land reptiles, but also those of such warm-blooded quadrupeds as frequent the banks of rivers, or, like the hippopotamus, inhabit their waters. Would not the same current of water which drifted down and rolled the bones of the lizards, tortoises, and fish of the

* See Fitton, Geol. Trans., Second Series, vol. iv. p. 328., and his references.

Wealden, have also swept down into the delta some fragments at least of mammiferous bones, had any animals of the highest class been then in existence? As a general rule, indeed, we cannot lay much stress on mere negative evidence; and, as we have seen, although so many teeth of the Iguanodon have been collected, it is only of late that a single small portion of a jaw of one of these gigantic lizards was obtained. Perhaps, in like manner, some bone or tooth of a fossil quadruped will one day be found. We may at least say, that we have at present no example of a continent covered with a luxurious vegetation, and forests inhabited by large saurians, both aquatic and terrestrial, and by birds, yet at the same time entirely destitute of warm-blooded quadrupeds. The nearest analogy to this state of things is that of New Zealand; and this fact will be more particularly alluded to in the sequel. (See Chap. XXIV.)

In conclusion I may remark, that from the time of the commencement of the Wealden, to far on in the Cretaceous period, we have signs of subsidence, and consequent diminution of land. But after the chalk was formed, or during the tertiary periods, we have, on the contrary, proofs of an increase of land in Europe. But we must not extend these generalizations to the whole surface

of the globe; for other large areas may have been growing more and more continental during the cretaceous, and more and more oceanic during the tertiary periods, the direction of the prevailing subterranean movement being reversed.

CHAPTER XIX.

DENUDATION OF THE CHALK AND WEALDEN.

Physical geography of certain districts composed of Cretaceous and Wealden strata — Lines of inland chalk-cliffs on the Seine in Normandy — Outstanding pillars and needles of chalk — Denudation of the chalk and Wealden in Surrey, Kent, and Sussex — Chalk once continuous from the North to the South Downs — Anticlinal axis and parallel ridges — Longitudinal and transverse valleys — Chalk escarpments — Rise and denudation of the strata gradual — Ridges formed by harder, valleys by softer beds —Why no alluvium, or wreck of the chalk, in the central district of the Weald — At what period the Weald valley was denuded — Elephant bed, Brighton.

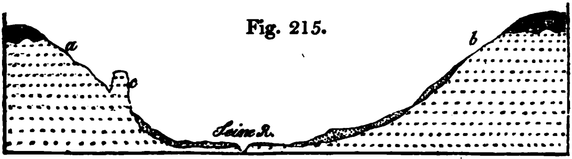
All the fossiliferous formations may be studied by the geologist in two distinct points of view: first, in reference to their position in the series, their mineral character and fossils; and, secondly, in regard to their physical geography, or the manner in which they now enter as mountain masses into the external structure of the earth.

Some account has already been given on the first head of the Cretaceous and Wealden strata, and we may now proceed to consider certain features in the physical geography of these groups as they occur in parts of England and France.

The hills composed of white chalk in the S. E. of England have a smooth rounded outline, and being usually in the state of sheep pastures, are free from trees or hedgerows; so that we have an opportunity of observing how the valleys by which they are drained ramify in all directions, and become wider and deeper as they descend. Although these valleys are now for the most part dry, except during heavy rains and the melting of snow, they may have been due to aqueous denudation, as explained in the sixth chapter; having been excavated when the chalk emerged gradually from the sea. This opinion is confirmed by the occasional occurrence of long lines of inland cliffs, in which the strata are cut off abruptly in a steep and often vertical precipice. The true nature of such escarpments is nowhere more obvious than in parts of Normandy, where the river Seine and its tributaries flow through deep winding valleys, hollowed out of chalk horizontally stratified. Thus, for example, if we follow the Seine for a distance of about 30 miles from Andelys to Elbœuf, we find the valley flanked on both sides by a steep slope of chalk, with numerous beds of

flint, the formation being laid open for a thickness of about 250 and 300 feet. Above the chalk is an overlying mass of tertiary sand, gravel, and clay, from 30 to 100 feet thick. The two opposite

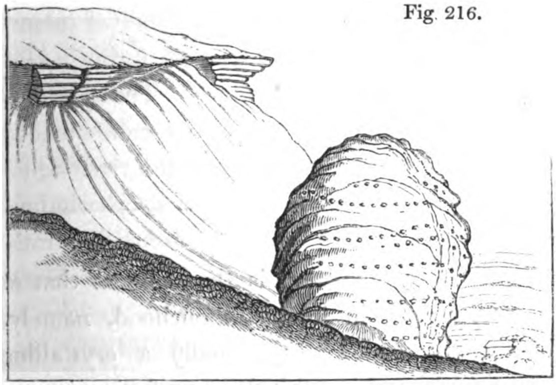
Fig. 215.



Section across Valley of Seine.

slopes of the hills *a* and *b*, where the chalk appears at the surface, are from two to four miles apart, and they are often perfectly smooth and even, like the steepest of our downs in England, but at many points they are broken by one, two, or more ranges of vertical, and even overhanging cliffs of bare white chalk with flints. At some

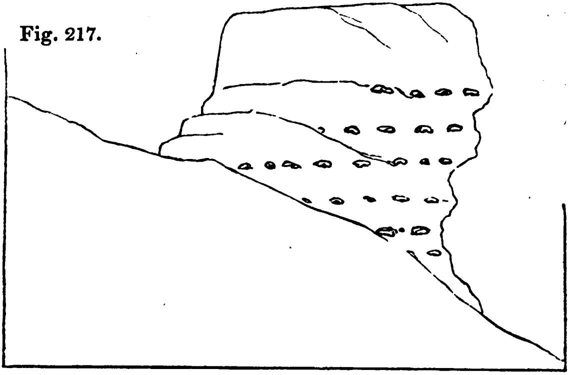
Fig. 216.



View of the Tête d'Homme, Andelys, seen from above.

points detached needles and pinnacles stand in the line of the cliffs, or in front of them, as at *c* (Fig. 215.). On the right bank of the Seine, at Andelys, one range about two miles long is seen, varying from 50 to 100 feet in perpendicular height, and having its continuity broken by a number of dry valleys or coombs, in one of which occurs a detached rock or needle, called the Tête d'Homme (see Figures). The top of this rock presents a precipitous face towards every point of the compass; its vertical height being more than 20 feet on the side of the downs, and 40 towards the Seine, the average diameter of the pillar being

Fig. 217.



Side view of the Tête d'Homme.

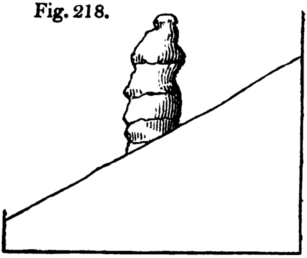
36 feet. Its composition is the same as that of the larger cliffs in its neighbourhood, namely, white chalk, having occasionally a crystalline texture like marble, with layers of flint in no-

dules and tabular masses. The flinty beds often project in relief four or five feet beyond the white chalk, which is generally in a state of slow decomposition, either exfoliating or being covered with white powder, like the chalk cliffs on the English coast; and, as in them, this superficial powder contains in some places common salt.

Other cliffs are situated on the right bank of the Seine, opposite Tournedos, between Andelys and Pont de l'Arche, where the precipices are from 50 to 80 feet high: several of their summits terminate in pinnacles; and one of them, in particular, is so completely detached as to present a perpendicular face 50 feet high towards the sloping down. On these cliffs several ledges are seen, which mark so many levels at which the waves of the sea may be supposed to have encroached for a long period. At a still greater height, immediately above the top of this range, are three much smaller cliffs, each about 4 feet high, with as many intervening terraces, which are continued so as to sweep in a semicircular form round an adjoining coomb, like those in Sicily before described (p. 155.).

If we then descend the river from Vatteville to a place called Senneville, we meet with a singular needle about 50 feet high, perfectly isolated on the escarpment of chalk on the right bank of the Seine. (See Fig. 218.) Another conspicuous range

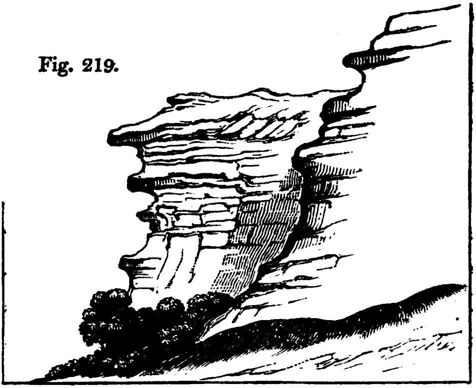
Fig. 218.



Chalk pinnacle at Senneville.

of inland cliffs is situated about twelve miles below, on the left bank of the Seine, beginning at Elbœuf, and comprehending the Roches d'Orival. (See Fig. 219.) Like those before described, it has an irregular surface, often overhanging, and with beds of flint

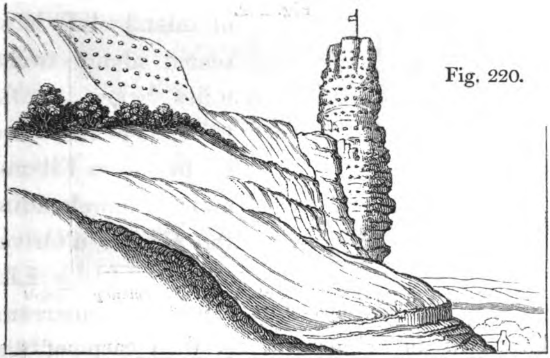
Fig. 219.



Roches d'Orival, Elbœuf.

projecting several feet. Like them, also, it exhibits a white powdery surface, and consists entirely of horizontal chalk with flints. Although forty miles inland, its base is only a few feet above the level of the Seine; its height, in some parts, exceeding 200 feet. It is broken, in one place, by a pyramidal mass or needle,

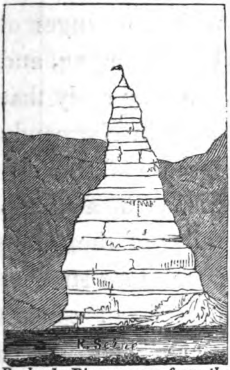
Fig. 220.



View of the Roche de Pignon, seen from the south.

called the Roche de Pignon, which stands out about 25 feet in front of the upper portion of the main cliffs, with which it is united by a narrow ridge about 40 feet lower than its summit. (See Figures.) Its height is about 200 feet; and, like the detached rocks before mentioned at Senneville, Vatteville, and Andelys, may be compared to those needles of chalk which occur on the coast of Normandy, as well as in the Isle of Wight and in Purbeck.* (See Fig. 222.)

Fig. 221.

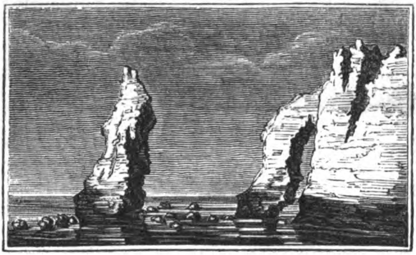


Roche de Pignon, seen from the river.

The foregoing description and drawings will

* An account of these cliffs was read by the author to the British Assoc. at Glasgow, Sept. 1840.

Fig. 222.



Needle and Arch of Etretat, in the chalk cliffs of Normandy. Height of Arch, 100 *feet.* (Passy.)*

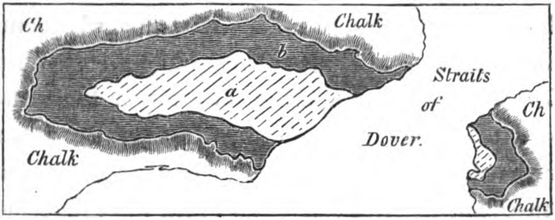
show, that the evidence of certain escarpments of the chalk having been originally sea-cliffs, is far more full and satisfactory in France than in England. If it be asked why, in the interior of our own country, we meet with no ranges of precipices equally vertical and overhanging, and no isolated pillars or needles, we may reply that the greater hardness of the chalk in Normandy may, in some measure, be the cause of this difference. But the frequent absence of all signs of littoral denudation in the valley of the Seine itself is a negative fact of a far more striking and perplexing character. The cliffs, after being almost continuous for miles, are then wholly wanting for much greater distances, being replaced by a green sloping down, although the beds remain of the same composition, and are equally horizontal; and although we may feel assured that the manner of the upheaval of the

* Seine-Inferieure, p. 142. and pl. 6. fig. 1.

land, whether intermittent or not, must have been the same at those intermediate points where no cliffs exist, as at others where they are so fully developed. But, in order to explain such apparent anomalies, the reader must refer again to the theory of denudation, as expounded in the 6th Chapter; where it was shown, first, that the undermining force of the waves and marine currents varies greatly at different parts of every coast; secondly, that precipitous rocks have often decomposed and crumbled down; and thirdly, that many terraces and small cliffs may now lie concealed beneath a talus of detrital matter.

Denudation of the Weald Valley. — No district is better fitted to illustrate the manner in which a great series of strata may have been upheaved and gradually denuded than the country intervening between the North and South Downs. This region, which is depicted in the accompanying map (from Mr. Greenough's large map of England), is between 40 and 50 miles in breadth; comprising within it the whole of Sussex, and parts of the counties of Kent, Surrey, and Hampshire. The space in which the formations older than the White Chalk, or those from the Gault to the Hastings sand inclusive, crop out, is bounded everywhere by a great escarpment of chalk, which is continued on the opposite side of the channel in the Bas Boulonnais in France, where it forms the semicircular

Fig. 223.



a b, beds older than the chalk.

boundary of a tract in which older strata also appear at the surface. (See Fig. 223.) The whole of this district may therefore be considered geologically as one and the same.

The five formations of the Weald Valley, indicated by different colours in the map, Plate 6., have been already described; and are, 1st, Chalk and Upper Green-sand; 2d, Gault, or blue calcareous marl; 3d, Lower Green-sand, consisting of greenish and ferruginous sands, with chert, and sometimes limestone; 4th, Weald Clay; 5th, Hastings Sands, composed chiefly of sand, clay, and sandstone.

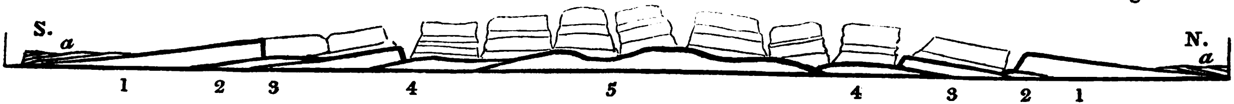
The space inclosed within the escarpment of the chalk affords an example of what has been technically called a "valley of denudation;" where the strata, partially removed by aqueous excavation, dip away on all sides from a central axis. Thus, it is supposed that the area now occupied by the Hastings sand (No. 5.) was once covered by the Weald clay (No. 4.), and this again by the

Green-sand (No. 3.), and this by the Gault (No. 2.); and lastly, that the chalk (No. 1.) extended originally over the whole space between the North and the South Downs. This theory will be better understood by consulting the annexed diagram (Fig. 224.), where the dark lines represent what now remains, and the fainter ones those portions of rock which are believed to have been carried away.

At each end of the diagram the tertiary strata (*a*) are exhibited reposing on the chalk. In the middle are seen the Hastings sands (No. 5.), forming an anticlinal axis, on each side of which the other formations are arranged with an opposite dip. It has been necessary, however, in order to give a clear view of the different formations, to exaggerate the proportional height of each in comparison to its horizontal extent; and a true scale is therefore subjoined in another diagram (Fig. 225.), in order to correct the erroneous impression which might otherwise be made on the reader's mind. In this section the distance between the North and South Downs is represented to exceed forty miles; for the Valley of the Weald is here intersected in its longest diameter, in the direction of a line between Lewes and Maidstone.

Through the central portion, then, of the district supposed to be denuded runs a great anti-

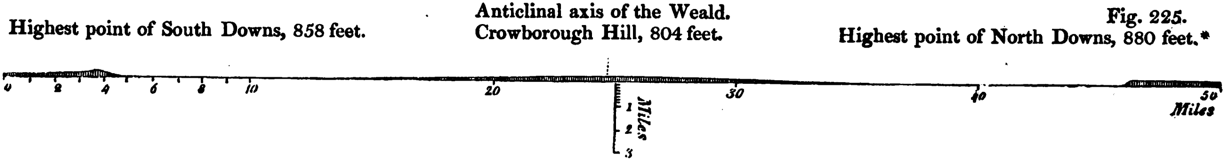
Fig. 224.



Section from the London to the Hampshire basin across the valley of the Weald.

a. Tertiary strata. 1. Chalk and firestone. 2. Gault. 3. Lower green-sand. 4. Weald clay. 5. Hastings sands.

Fig. 225.



Section of the country from the confines of the basin of London to that of Hants, with the principal heights above the level of the sea on a true scale.†

* Botley Hill, near Godstone, in Surrey, was found by trigonometrical measurement to be 880 feet above the level of the sea; and Wrotham Hill, near Maidstone, which appears to be next in height of the North Downs, 795 feet.

† My friend Mr. Mantell has kindly drawn up this scale at my request.

clinal line, having a direction nearly east and west, on both sides of which the beds 4, 3, 2, and 1, crop out in succession. But, although, for the sake of rendering the physical structure of this region more intelligible, the central line of elevation has alone been introduced, as in the diagrams of Smith, Mantell, Conybeare, and others, geologists have always been well aware that numerous minor lines of dislocation and flexure run parallel to the great central axis.

In the central area of the Hastings Sand the strata have undergone the greatest displacement; one fault being known, where the vertical shift of a bed of calcareous grit is no less than sixty fathoms.* Much of the picturesque scenery of this district arises from the depth of the narrow valleys and ridges to which the sharp bends and fractures of the strata have given rise; but it is also in part to be attributed to the excavating power exerted by water, especially on the interstratified argillaceous beds.

Besides the series of longitudinal valleys and ridges in the Weald, there are valleys which run in a transverse direction, passing through the chalk to the basin of the Thames on the one side, and to the English channel on the other. In this manner the chain of the North Downs is broken by the rivers Wey, Mole, Darent,

* Fitton, Geol. of Hastings, p. 55.

Medway, and Stour; the South Downs by the Arun, Adur, Ouse, and Cuckmere.* If these transverse hollows could be filled up, all the rivers, observes Mr. Conybeare, would be forced to take an easterly course, and to empty themselves into the sea by Romney Marsh and Pevensey Levels.†

Mr. Martin has suggested that the great cross fractures of the chalk, which have become river channels, have a remarkable correspondence on each side of the valley of the Weald; in several instances the gorges in the North and South Downs appearing to be directly opposed to each other. Thus, for example, the defiles of the Wey in the North Downs, and of the Arun in the South, seem to coincide in direction; and, in like manner, the Ouse corresponds to the Darent, and the Cuckmere to the Medway.‡

Although these coincidences may, perhaps, be accidental, it is by no means improbable, as hinted by the author above mentioned, that the great amount of elevation towards the centre of the Weald district gave rise to transverse fissures. And as the longitudinal valleys were connected with that linear movement which caused the anticlinal lines running east and west, so the cross fissures might have been occasioned by the inten-

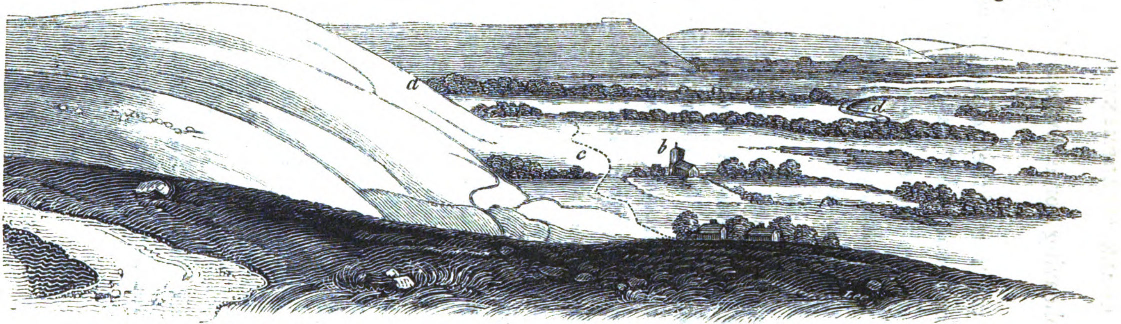
* Conybeare, Outlines of Geol., p. 81. † Ibid., p. 145.
‡ Geol. of Western Sussex, p. 61.

sity of the upheaving force towards the centre of the line.

But before treating of the manner in which the upheaving movement may have acted, I shall endeavour to make the reader more intimately acquainted with the leading geographical features of the district, so far as they are of geological interest.

In whatever direction we travel from the tertiary strata of the basins of London and Hampshire (see Map, plate 6.) towards the valley of the Weald, we first ascend a slope of white chalk, with flints, and then find ourselves on the summit of a declivity consisting, for the most part, of different members of the chalk formation; below which the upper green-sand, and sometimes, also, the gault, crop out. This steep declivity is the great escarpment of the chalk before mentioned, which overhangs a valley excavated chiefly out of the argillaceous or marly bed, termed Gault (No. 2.). The escarpment is continuous along the southern termination of the North Downs, and may be traced from the sea, at Folkstone, westward to Guildford and the neighbourhood of Petersfield, and from thence to the termination of the South Downs at Beachy Head. In this precipice or steep slope the strata are cut off abruptly, and it is evident that they must originally have extended farther. In the accom-

Fig. 226.



View of the chalk escarpment of the South Downs. Taken from the Devil'sDike, looking towards the west and south-west.

a. The town of Steyning is hidden by this point. *b.* Edburton church. *c.* Road. *d.* River Adur.

panying wood-cut (Fig. 226.), part of the escarpment of the South Downs is faithfully represented, where the denudation at the base of the declivity has been somewhat more extensive than usual, in consequence of the upper and lower green-sand being formed of very incoherent materials, the upper, indeed, being extremely thin and almost wanting.

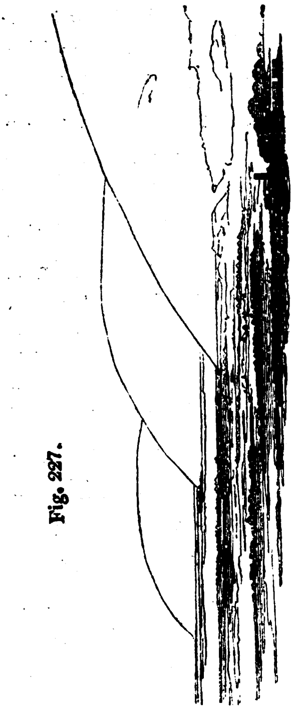


Fig. 227.

Chalk escarpment, as seen from the hill above Steyning, Sussex. The castle and village of Bramber in the foreground.

The geologist cannot fail to recognize in this view the exact likeness of a sea-cliff; and if he turns and looks in an opposite direction, or eastward, towards Beachy Head (see Fig. 227.), he will see the same line of heights prolonged. Even those who are not accustomed to speculate on the former changes which the surface has undergone may fancy the broad and level plain to resemble the flat sands which were laid dry by the receding

tide, and the different projecting masses of chalk to be the headlands of a coast which separated the different bays from each other.

In regard to the transverse valleys before mentioned, as intersecting the chalk hills, some idea of them may be derived from the subjoined sketch (Fig. 228.) of the gorge of the river Adur, taken from the summit of the chalk downs, at a point in the bridle-way leading from the towns of Bramber and Steyning to Shoreham. If the reader will refer again to the view given in a former wood-cut (Fig. 226. p. 16.), he will there see the exact point where the gorge of which I am now speaking interrupts the chalk escarpment. A projecting hill, at the point *a*, hides the town of Steyning, near which the valley commences where the Adur passes directly to the sea at Old Shoreham. The river flows through a nearly level plain, as do most of the others which intersect the hills of Surrey, Kent, and Sussex; and it is evident that these openings, so far at least as they are due to aqueous erosion, have not been produced by the rivers, many of which, like the Ouse near Lewes, have filled up arms of the sea, instead of deepening the hollows which they traverse.

Now, in order to account for the manner in which the five groups of strata, 1, 2, 3, 4, 5, represented in the Map, plate 6., and in the section Fig. 224., may have been brought into their

Fig. 228.

Transverse Valley of the Adur in the South Downs.

a. Town of Steyning. *b.* River Adur. c. Old Shoreham.

present position, the following hypothesis has been very generally adopted: — Suppose the five formations to lie in horizontal stratification at the bottom of the sea; then let a movement from below press them upwards into the form of a flattened dome, and let the crown of this dome be afterwards cut off, so that the incision should penetrate to the lowest of the five groups. The different beds would then be exposed on the surface, in the manner exhibited in the map, plate 6.*

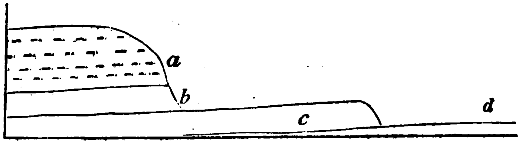
The quantity of denudation or removal by water of stratified masses assumed to have once reached continuously from the North to the South Downs is so enormous, that the reader may at first be startled by the boldness of the hypothesis. But the difficulty vanishes when once sufficient time is allowed for the gradual and successive rise of the strata, during which the waves and currents of the ocean might slowly accomplish an operation, which no sudden diluvial rush of waters could possibly have effected.

Among other proofs of the action of water, it may be stated that the great longitudinal valleys follow the outcrop of the softer and more incoherent beds, while ridges or lines of cliff usually occur at those points where the strata are com-

* See illustrations of this theory by Dr. Fitton, Geol. Sketch of Hastings.

posed of harder stone. Thus, for example, the chalk with flints, together with the subjacent upper green-sand, which is often used for building, under the provincial name of "firestone," has been cut into a steep cliff on that side on which the sea encroached. This escarpment bounds a deep valley, excavated chiefly out of the soft argillaceous or marly bed, termed gault (No. 2.). In some places the upper green-sand is in a loose and incoherent state, and there it has been as much denuded as the gault; as, for example, near Beachy Head; but farther to the westward it is of great thickness, and contains hard beds of blue chert and calcareous sandstone or firestone. Here, accordingly, we find that it produces a corresponding influence on the scenery of the country; for it runs out like a step beyond the foot of the chalk-hills, and constitutes a lower terrace, varying in breadth from a quarter of a mile to three miles, and following the sinuosities of the chalk escarpment.*

Fig. 229.



a. Chalk with flints. *b.* Chalk without flints.
c. Upper green-sand, or firestone. *d.* Gault.

* Mr. Murchison, Geol. Sketch of Sussex, &c., Geol. Trans., Second Series, vol. ii. p. 98.

It is impossible to desire a more satisfactory proof that the escarpment is due to the excavating power of water during the rise of the strata; for I have shown, in my account of the coast of Sicily, in what manner the encroachments of the sea tend to efface that succession of terraces which must otherwise result from the intermittent upheaval of a coast preyed upon by the waves.* During the interval between two elevatory movements, the lower terrace will usually be destroyed, wherever it is composed of incoherent materials; whereas the sea will not have time entirely to sweep away another part of the same terrace, or lower platform, which happens to be composed of rocks of a harder texture, and capable of offering a firmer resistance to the erosive action of water. As the yielding clay termed gault would be readily washed away, we find its outcrop marked everywhere by a valley which skirts the base of the chalk hills, and which is usually bounded on the opposite side by the lower green-sand; but as the upper beds of this last formation are most commonly loose and incoherent, they also have usually disappeared and increased the breadth of the valley. But in those districts where chert, limestone, and other solid materials enter largely into the composition of this formation (No. 3.), they

* See p.153.

give rise to a range of hills parallel to the chalk, which sometimes rival the escarpment of the chalk itself in height, or even surpass it, as in Leith Hill, near Dorking. This ridge often presents a steep escarpment towards the soft argillaceous deposit called the Weald clay (No. 4; see the strong lines in Fig. 224. p. 12.), which usually forms a broad valley, separating the lower green-sand from the Hastings sands or Forest ridge; but where subordinate beds of sandstone of a firmer texture occur, the uniformity of the plain of No. 4. is broken by waving irregularities and hillocks.

It will be easy to shew how closely these superficial inequalities agree with those which we might naturally expect to originate during the gradual rise of the Wealden district. Suppose the line of the most energetic movement to have coincided with what is now the central ridge of the Weald valley; in that case the first land which emerged must have been situated where the Forest ridge is now placed. Here many shoals and reefs may first have existed, and islands of chalk devoured in the course of ages by the ocean (see Fig. 225.); so that the top of the shattered dome which first appeared above water may have been utterly destroyed, and the masses represented by the fainter lines (Fig. 225.) removed.

The upper green-sand is represented as forming on the left hand a single precipice with the

chalk; while on the right there are two cliffs, with an intervening terrace, as before described in

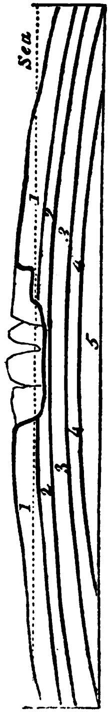


Fig. 230.

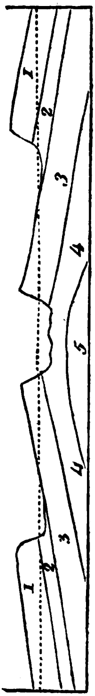


Fig. 231.

The dotted lines represent the sea-level.

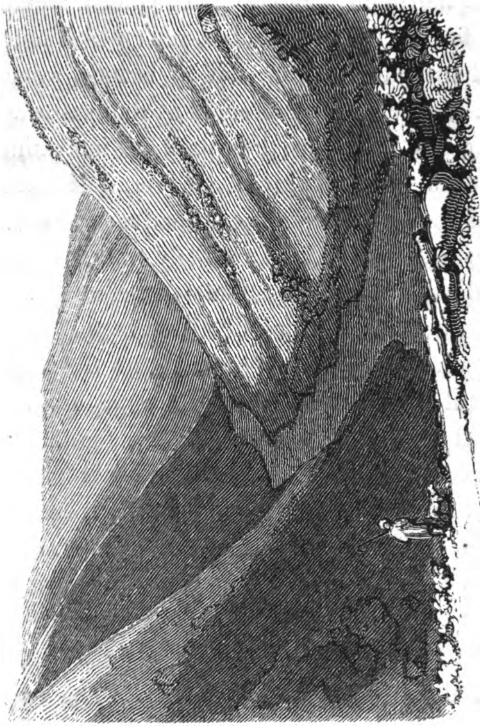
Fig. 229. p. 21. Two strips of land would then remain on each side of a channel; in the same manner as the opposite coasts of France and England, composed of chalk, present ranges of white cliffs facing each other. A powerful current might then rush, like that which now ebbs

and flows through the Straits of Dover, and might scoop out a channel in the gault (No. 2.). This softer bed would yield with ease in proportion as parts of it were brought up from time to time and exposed to the fury of the waves, so that large spaces occupied by the harder formation or Green Sand (No. 3.) would be laid bare. This last rock opposing a more effectual resistance would next emerge; while the Chalk cliffs, at the base of which the gault is rapidly undermined, would recede farther from each other, after which four parallel strips of land, or rows of islands, would be caused, which are represented by the masses which in Fig. 231. rise above the dotted line indicating the sea-level. In this diagram, however, the inclination of the upper surface of the formations (Nos. 1. and 3.) is exaggerated. Originally this surface must have been level, like the submarine terraces produced by denudation, and described before (p. 149.); but they were afterwards more and more tilted by that general movement to which the region of the Weald owes its structure. At length, by the further elevation of the dome-shaped mass, the clay (No. 4.) would be brought within reach of the waves, which would probably gain the more easy access to the subjacent deposit by the rents which would be caused in No. 3., and in the central part of the ridge where the uplifting force had been exerted with the greatest energy. The opposite

cliffs, in which the Green Sand (No. 3.) terminate, would now begin to recede from each other, having at their base a yielding stratum of clay (No. 4.) Lastly, the sea would penetrate to the sand (No. 5.), and then the state of things indicated in the dark lines of the upper section, Fig. 224., would be consummated.

It was stated that there are many lines of flexure and dislocation, running east and west, or

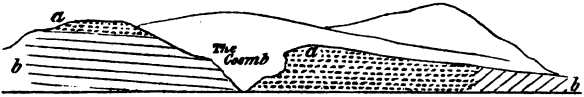
Fig. 232.



The Coomb, near Lewes.

parallel to the central axis of the Wealden. They are numerous in the district of the Hastings sand, and sometimes occur in the Chalk itself. One of the latter kind has given rise to the ravine called the Coomb, near Lewes, and was first traced out by Mr. Mantell, in whose company I examined it. This coomb is seen on the eastern side of the valley of the Ouse, in the suburbs of the town of Lewes. The steep declivities on each side are covered with green turf, as is the bottom, which is perfectly dry. No outward signs of disturbance are visible; and the connection of the hollow with subterranean movements would not have been suspected by the geologist, had not the evidence of great convulsions been clearly exposed in the escarpment of the valley of the Ouse, and the numerous chalk pits worked at the termination of the Coomb. By aid of these we discover that the ravine coincides precisely with a line of fault, on one side of which the chalk with flints (*a*), appears at the summit of the hill, while it is thrown down to the bottom on the other.

Fig. 233.



Fault in the cliff-hills near Lewes. Mantell.

a. Chalk with flints. *b.* Lower chalk.*

* For farther information, see Mantell's Geol. of S.E. of England, p. 352.

Mr. Martin, in his work on the geology of Western Sussex, published in 1828, threw much light on the structure of the Wealden by tracing out continuously for miles the direction of many anticlinal lines and cross fractures; and the same course of investigation has since been followed out in greater detail by Mr. Hopkins. The mathematician last mentioned has shown that the observed direction of the lines of flexure and dislocation in the Weald district coincide with those which might have been anticipated theoretically on mechanical principles, if we assume certain simple conditions under which the strata were lifted up by an expansive subterranean force. He finds by calculation that if this force was applied so as to act uniformly upwards within an elliptic area, the longitudinal fissures thereby produced would nearly coincide with the outlines of the ellipse, forming cracks, which are portions of smaller concentric ellipses, parallel to the margin of the larger one. These longitudinal fissures would also be intercepted by others running at right angles to them, and both lines of fracture may have been produced at the same time.* In this illustration it is supposed that the expansive force acted simultaneously and with equal intensity at every point within the upheaved area, and not with greater energy along the central axis or region of principal elevation.

* Geol. Soc. Proceedings, No. 74. p. 363. 1841.

The geologist cannot fail to derive great advantage in his speculations from the mathematical investigation of a problem of this kind, where results free from all uncertainty are obtained on the assumption of certain simple conditions. Such results, when once ascertained by mathematical methods, may serve as standard cases, to which others occurring in nature of a more complicated kind may be referred. But in order that a uniform force should cause the strata to attain in the centre of the ellipse a height so far exceeding (especially before denudation) that which they have reached round the margin, it is necessary to assume that the mass of upheaved strata offered originally a very unequal degree of resistance to the subterranean force, either from being more fractured in one place than in another, or from being pressed down by a less weight of incumbent strata. It is suggested that they may have been acted upon somewhat in the manner of a carpet spread out loosely on a floor, and nailed down round the edges, which would swell into the shape of a dome if pressed up equally at every point by air admitted from beneath. But when we are reasoning on the particular phenomena of the Weald, we have no geological data for determining whether it be more probable that originally the resistance to be overcome was so extremely unequal in different places, or

whether the subterranean force, instead of being everywhere uniform, was not applied with very different degrees of intensity beneath distinct portions of the upraised area.

The opinion that both the longitudinal and transverse lines of fracture may have been produced simultaneously, accords well with that expressed by M. Thurmann, in his work on the anticlinal ridges and valleys of elevation of the Bernese Jura.* For the accuracy of his map and sections I can vouch, from personal examination, in 1835, of part of the region surveyed by him. Among other results, at which this author arrived, it appears that the breadth of all the numerous anticlinal ridges and dome-shaped masses in the Jura is invariably great in proportion to the number of the formations exposed to view; or, in other words, to the depth to which the superimposed groups of secondary strata have been laid open. (See Fig. 70. p. 118. for structure of Jura.) He also remarks, that the anticlinal lines are occasionally oblique and cross each other, in which case the greatest dislocation of the beds takes place. Some of the cross fractures are imagined by him to have been contemporaneous, others subsequent to the longitudinal ones.

I have assumed, in the former part of this

* Soulèvemens Jurassiques. Paris, 1832.

chapter, that the rise of the Weald was gradual, whereas many geologists have attributed its elevation to a single effort of subterranean violence. There appears to them such a unity of effect in this and other lines of deranged strata in the south-east of England, such as that of the Isle of Wight, as is inconsistent with the supposition of a great number of separate movements recurring after long intervals of time. But we know that earthquakes are repeated throughout a long series of ages, in the same spots, like volcanic eruptions. The oldest lavas of Etna were poured out many thousands, perhaps myriads of years, before the newest, and yet they, and the movements accompanying their emission, have produced a symmetrical mountain; and if rivers of melted matter thus continue to flow in the same direction, and towards the same point, for an indefinite lapse of ages, what difficulty is there in conceiving that the subterranean volcanic force, occasioning the rise or fall of certain parts of the earth's crust, may, by reiterated movements, produce the most perfect unity of result?

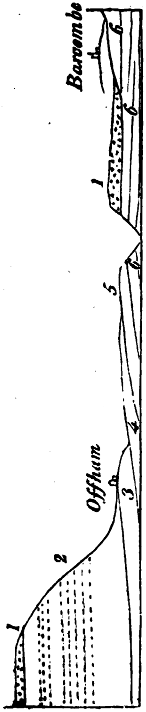
Alluvium of the Weald.—Our next inquiry may be directed to the alluvium strewed over the surface of the supposed area of denudation. Has any wreck been left behind of the strata removed? To this we may answer, 1st, that the summit of the chalk downs are covered every where with gravel

composed of partially rounded chalk flints, such as might remain after masses of white chalk had been softened and removed by the sea, the harder materials of the siliceous strata not being carried away. But it is remarkable, that similar gravel is usually wanting in the deep longitudinal valleys at the foot of the chalk escarpment, although, in some few instances, the detritus of the chalk has been traced in patches over the gault, and even the lower green-sand, for a distance of several miles from the escarpment of the north and south downs. But no vestige of the chalk and its flints have been seen on the central ridge of the Weald or the Hastings sands, but merely gravel derived from the rocks immediately subjacent. This distribution of alluvium, and especially the absence of chalk detritus in the central district, agrees well with the theory of denudation before set forth; for, to return to Fig. 230., if the chalk (No. 1.) were once continuous and covered every where with flint gravel, this superficial covering would be the first to be carried away from the highest part of the dome long before any of the gault (No. 2.) was laid bare. Now if some ruins of the chalk remain at first on the gault, these would be, in a great degree, cleared away before any part of the lower green-sand (No. 3.) is denuded. Thus in proportion to the number and thickness of the groups removed in succession, is

the probability lessened of our finding any remnants of the highest group strewed over the bared surface of the lowest.

As an exception to the general rule of the small distance to which any wreck of the chalk can be traced from the escarpments of the North and South Downs, I may mention a thick bed of chalk flints which occurs near Barcombe, about three miles to the north of Lewes (see Fig. 234.), a

Fig. 234.



Section from the North escarpment of the South Downs to Barcombe.

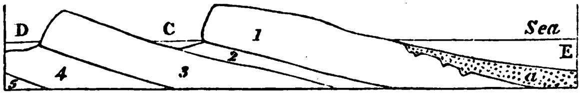
1. Gravel composed of partially rounded chalk flints.
2. Chalk with and without flints.
3. Lowest chalk or chalk marl (upper green-sand wanting).
4. Gault. 5. Lower green-sand. 6. Weald clay.

place which I visited with Mr. Mantell, to whom I am indebted for the accompanying section. Even here it will be seen that the gravel reaches no farther than the Weald Clay. The same section shows one of the minor east and west anticlinal lines before alluded to (p. 13.).

At what period the Weald Valley was denuded.— If we inquire at what geological period the denudation of the Weald was effected, we shall immediately perceive that the question is limited to this point, whether it took place during or subsequent to the deposition of the Eocene strata of the south of England. For in the basins of London and Hampshire the Eocene strata are conformable to the chalk, being horizontal where the beds of chalk are horizontal, and vertical where they are vertical, so that both series of rocks appear to have participated in nearly the same movements. At the eastern extremity of the Isle of Wight some beds even of the freshwater series, have been thrown on their edges, like those of the London clay. Nevertheless we can by no means infer that the tertiary deposits of the London and Hampshire basins once extended like the chalk over the entire valley of the Weald, because the denudation of the chalk and greensand may have been going on in the centre of that area, while contiguous parts of the sea were sufficiently deep to receive and retain the matter derived from that waste.

Thus while the waves and currents were excavating the longitudinal valleys D and C (Fig. 235.), the deposits *a* may have been thrown down

Fig. 235.



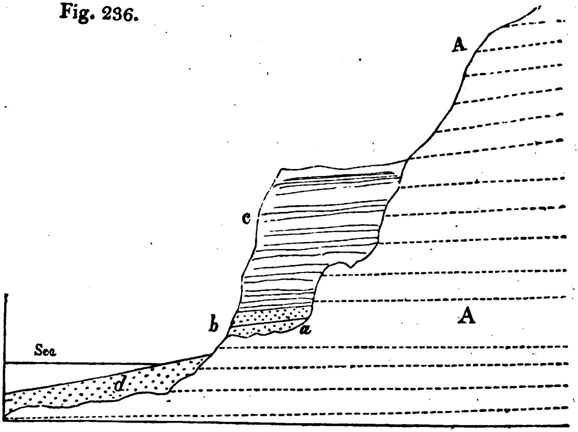
to the bottom of the contiguous deep water E, the sediment being drifted through tranverse fissures, as before explained. In this case, the rise of the formations Nos. 1, 2, 3, 4, 5, may have been going on contemporaneously with the excavation of the valleys C and D, and with the accumulation of the strata *a*.

This idea receives some countenance from the fact of the tertiary strata, at their junction with the chalk and the London and Hampshire basins, often consisting of dense beds of sand and shingle, as the Addington Hills near Croydon. They also contain occasionally fresh-water shells and the remains of land animals and plants, which indicate the former presence of land at no great distance, some part of which may have occupied the centre of the Weald.

Nevertheless, a great portion of the upheaval and denudation of the south-eastern part of England was certainly posterior in date to the deposition of the London clay, because patches of that

formation reach to a great height on the chalk. But it would lead me into too wide a digression were I fully to discuss this question at present; and I must refer to what I have said when treating of mountain-chains in the Principles of Geology, to show how difficult is the determination of the relative dates of the disturbance of strata. Eocene deposits may have been uplifted to great heights before the close of the Eocene period, or

Fig. 236.



A. Chalk with layers of flint dipping slightly to the south.

b. Ancient beach, consisting of fine sand, from one to four feet thick, covered by shingle from five to eight feet thick of pebbles of chalk-flint, granite, and other rocks, with broken shells, &c.

c. Elephant bed, about fifty feet thick, consisting of layers of white chalk rubble, with broken chalk flints, in which deposit are found bones of ox, deer, horse, and mammoth.

d. Sand and shingle of modern beach.

before the living species of that era had passed away from the earth.

We may, however, affirm with confidence, that considerable movements of elevation have been experienced in the south-east of England, at periods decidedly post-Eocene; as, for example, those by which the Crag strata attained their present position above the sea in Norfolk, Suffolk, and Essex. The formation also called by Mr. Mantell the Elephant Bed, at the foot of the chalk cliffs at Brighton, is not merely a talus of calcareous rubble collected at the base of an inland cliff, but exhibits every appearance of having been spread out in successive horizontal layers by water in motion.

The deposit alluded to skirts the shores between Brighton and Rottingdean, and another mass apparently of the same age occurs at Dover. The phenomena appear to me to suggest the following conclusions:—First, the south-eastern part of England had acquired its actual configuration when the ancient chalk cliff A *a* was formed, the beach of sand and shingle *b* having then been thrown up at the base of the cliff. Afterwards the whole coast, or at least that part of it where the elephant bed now extends, subsided to the depth of fifty or sixty feet; and during the period of submergence successive layers of white calcareous rubble *c* were accumulated, so as to cover the ancient beach *b*. Subsequently, the coast

was again raised, so that the ancient shore was elevated to a level somewhat higher than its original position.*

* See Mantell's Geol. of S. E. of England, p. 32. After re-examining the elephant bed in 1834, I was no longer in doubt of its having been a regular subaqueous deposit.

CHAPTER XX.

OOLITE AND LIAS.

Subdivisions of the Oolitic groups — Fossil shells — Corals in the calcareous divisions only — Buried forest of Encrinites in Bradford clay — Changes in organic life — Characteristic fossils — Signs of neighbouring land and shoals — Supposed cetacea in Oolite — Oolite of Yorkshire and Scotland.

Oolite. — Below the fresh-water group called the Wealden, or, where this is wanting, immediately beneath the Cretaceous formation, a great series of marine strata, commonly called "the Oolite," occurs in many parts of Europe. This group has been so named, because, in England and other places where it was first examined, the limestones belonging to it had an oolitic structure (see p. 26.). These rocks occupy in England a zone which is nearly thirty miles in average breadth, and extends across the island, from Yorkshire on the north-east, to Dorsetshire on the south-west.* Their mineral characters are not uniform throughout this region; but the following are the names

* For details respecting this formation in England, see Conybeare and Phillips's Geology, chap. iii.

of the principal subdivisions observed in the central and south-eastern parts of England:—

OOLITE.

Upper	*a.*	Portland stone and sand.
	b.	Kimmeridge clay.
Middle	*c.*	Coral rag.
	d.	Oxford clay.
Lower	*e.*	Cornbrash and Forest Marble.
	f.	Great Oolite and Stonesfield slate.
	g.	Fuller's earth.
	h.	Inferior Oolite.

The Lias then succeeds to the Inferior Oolite.

The upper oolitic system of the above Table has usually the Kimmeridge clay for its base, and the middle oolitic system the Oxford clay. The lower system reposes on the Lias, an argillo-calcareous formation, which some include in the lower oolite, but which will be treated of separately in the next chapter. Many of these subdivisions are distinguished by peculiar organic remains; and though varying in thickness, may be traced in certain directions for great distances, especially if we compare the part of England to which the above-mentioned type refers with the north-west of France, and the Jura mountains, which separate that country from Switzerland, and in which, though distant above 400 geographical miles, the analogy to the English type above mentioned is more perfect than in Yorkshire or Normandy.

To enter upon a systematic description of this complicated series of strata would require many chapters; the following facts, therefore, are selected from a multitude of others, with a view of illustrating the origin of the oolitic rocks, and of showing the state of organic life and geographical condition of part of the globe when they were formed.

In almost all the minor divisions enumerated in the above Table, *Ammonites* and *Belemnites* are found (see Figs. 253. 255.), but of species different from those of the cretaceous period. The *ammonites* are of various sizes, from the size of a small carriage-wheel to less than an inch diameter.

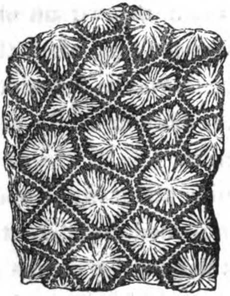
It is not uncommon to find *belemnites* in different members of the series, with full-grown *serpulæ* attached to them. As these shells, like the bone of the cuttle-fish, so often thrown on our shores, were internal, it is clear that after the death of the cephalopod the *belemnite* remained for some time unburied at the bottom of the sea, so that the *serpulæ* grew upon it.

These cephalopoda, swimming about in the open sea, left their shells to be imbedded indifferently in whatever sediment was then in the course of deposition, whether calcareous or argillaceous. But the corals are almost entirely confined to the limestones, and are wanting in the dense formations of interposed clay, as also in the Lias, these zoophytes

requiring not only carbonate of lime for their support, and clear water, but a bottom remaining for years unchanged, either by the shifting of sand or the accession of fresh sediment.

In the Upper Oolite of England, corals are rare, although one species is found plentifully at Tisbury, in Wiltshire, in the Portland sand converted into flint and chert, the original calcareous matter being replaced by silex. (Fig. 237.) One of the limestones of the Middle Oolite has been called the "Coral Rag," because it consists, in part, of continuous beds of petrified corals, for the most part retaining the position in which they grew at the bottom of the sea. They belong chiefly to the genera *Caryophyllia* (Fig. 238.), *Agaricia*, and

Fig. 237.



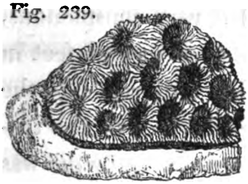
Columnaria oblonga, Blainv.
Upper Oolite, Tisbury.

Fig. 238.

Caryophyllia annularis, Parkin.
Coral rag, Steeple Ashton.

Astrea, and sometimes form masses of coral fifteen feet thick. In the annexed figure of an *Astrea*,

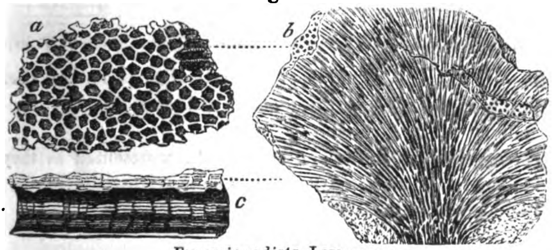
Fig. 239.



Astrea; Coral Rag.

from this formation, it will be seen that the cup-shaped cavities are deepest on the right-hand side, and that they grow more and more shallow, till those on the left side are nearly filled up. The last-named stars are supposed to be Polyparia of advanced age. These coralline strata extend through the calcareous hills of the N.W. of Berkshire, and north of Wilts, and again recur in Yorkshire, near Scarborough. Although the name of coral rag has been thus appropriated, there are portions of the lower oolite, as for example, the Great and Inferior Oolite (*f. h.* Table, p. 40.), which are equally intitled in many places to be called coralline limestones. Thus the Great Oolite near Bath contains various corals, among which the

Fig. 240.



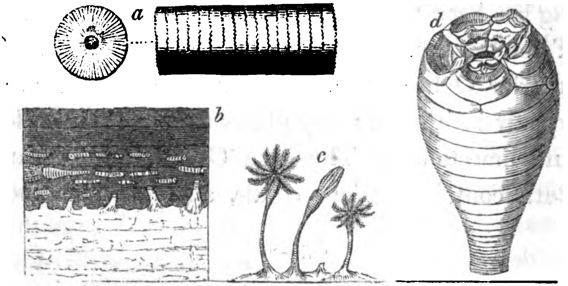
Eunomia radiata, Lamouroux.

a. section transverse to the tubes.
b. vertical section, showing the radiation of the tubes.
c. portion of interior of tubes magnified, showing striated surface.

Eunomia radiata (Fig. 240.) is very conspicuous, single individuals forming masses several feet in diameter; and having probably required, like the large existing brain-coral (*Meandrina*) of the tropics, many centuries before their growth was completed.

Different species of *Crinoideans*, or stone-lilies, are also common in the same rocks with corals; and, like them, must have enjoyed a firm bottom, where their root, or base of attachment, remained undisturbed for years (*c.* Fig. 241.). Such fossils,

Fig. 241.



Apiocrinites rotundus, or Pear Encrinite; Miller. Fossil at Bradford, Wilts.

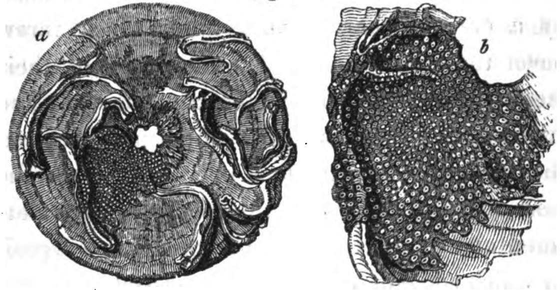
a. Stem of *Apiocrinites*, and one of the articulations, natural size.
b. Section at Bradford of great oolite and overlying clay, containing the fossil encrinites. See text.
c. Three perfect individuals of *Apiocrinites*, represented as they grew on the surface of the Great Oolite.
d. Body of the *Apiocrinites rotundus*.

therefore, are almost confined to the limestones; but an exception occurs at Bradford, near Bath, where they are enveloped in clay. In this case,

however, it appears that the solid upper surface of the "Great Oolite" had supported, for a time, a thick submarine forest of these beautiful zoophytes, until the clear and still water was invaded by a current charged with mud, which threw down the stone-lilies, and broke most of their stems short off near the point of attachment. The stumps still remain in their original position; but the numerous articulations once composing the stem, arms, and body of the zoophyte, were scattered at random through the argillaceous deposit in which some of them now lie prostrate. These appearances are represented in the section *b*, Fig. 241., where the darker strata represent the Bradford clay, a member of the Forest marble (*e*. Table, p. 40.). The upper surface of the calcareous stone below is completely incrusted over with a continuous pavement, formed by the stony roots or attachments of the Crinoidea; and besides this evidence of the length of time they had lived on the spot, we find great numbers of single joints, or circular plates of the stem and body of the encrinite, covered over with *serpulæ*. Now these *serpulæ* could only have begun to grow after the death of some of the stone-lilies, parts of whose skeletons had been strewed over the floor of the ocean before the irruption of argillaceous mud. In some instances we find that, after the parasitic *serpulæ* were full grown, they had become incrusted over with a coral, called *Berenicea diluviana;* and

many generations of these polyps had succeeded each other in the pure water before they became fossil.

Fig. 242.



a. Single plate, or articulation of an Encrinite overgrown with *serpulæ* and corals. Natural size. Bradford clay.
b. Portion of the same magnified, showing the coral *Berenicea diluviana* covering one of the *serpulæ.*

We may, therefore, perceive distinctly that, as the pines and cycadeous plants of the ancient Portland Forest were killed by submergence under fresh water, and soon buried beneath muddy sediment, so an invasion of argillaceous matter put a sudden stop to the growth of the Bradford Encrinites, and led to their preservation in marine strata.*

Such differences in the fossils as distinguish the calcareous and argillaceous deposits from each other, would be described by naturalists as arising out of a difference in the *stations* of species; but

* For a fuller account of these Encrinites, see Buckland's Bridgewater Treatise, vol. i. p. 429.

besides these, there are variations in the fossils of the higher, middle, and lower part of the oolitic series, which must be ascribed to that great law of change in organic life by which distinct assemblages of species have been adapted, at successive geological periods, to the varying conditions of the habitable surface. In a single district it is difficult to decide how far the limitation of species to certain minor formations has been due to the local influence of *stations*, or how far it has been caused by time, or the creative and destroying law above alluded to. But we recognize the reality of the last-mentioned influence, when we contrast the whole oolitic series of England with that of parts of the Jura, Alps, and other distant regions, where there is scarcely any lithological resemblance; and yet some of the same fossils remain peculiar in each country to the Upper, Middle, and Lower Oolite formations respectively. Mr. Thurmann has shown how remarkably this fact holds true in the Bernese Jura, although the argillaceous divisions, so conspicuous in England, are feebly represented there, and some entirely wanting.

Amongst the characteristic fossils of the Upper Oolite, may be mentioned the *Ostrea deltoidea* (Fig. 244.), found in the Kimmeridge clay throughout England and the north of France, and also in Scotland, near Brora. The *Gryphæa virgula*

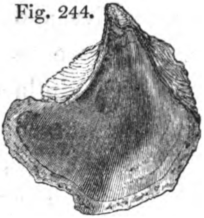
(Fig. 243.), also met with in the same clay near Oxford, and so abundant in the upper oolite of parts of France as to have caused the deposit to be termed "marnes à gryphées virgules." Near Clermont, in Argonne, a few leagues from St. Menehould, these indurated marls crop out from beneath the gault; and, on decomposing, leave

FOSSILS OF THE OOLITE.

Fig. 243.

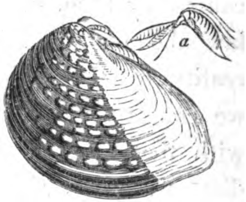
Gryphæa virgula.

Fig. 244.



Ostrea deltoidea.
Upper Oolite. ¼ nat. size.

Fig. 245.

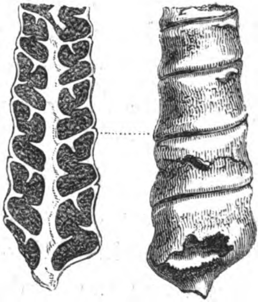


Trigonia gibbosa. ⅓ nat. size.
a. the hinge.
Portland Oolite, Tisbury.

Fig. 246.

Nerinæa hieroglyphica.
Coral rag.

Fig. 247.

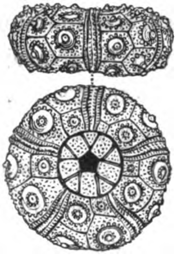


Nerinæa Goodhallii, Fitton.
Coral rag, Weymouth. ¼ nat. size.

Fig. 248.

Cast of Diceras arietina.
Coral rag.

Fig. 249.



Cidaris coronata.
Coral rag.

the surface of every ploughed field literally strewed over with fossil oysters.

One of the limestones of the Jura, referred to the age of the English coral rag, has been called "Nerinæan limestone" (Calcaire à Nérinées) by M. Thirria; *Nerinæa* being an extinct genus of univalve shells, much resembling the *Cerithium* in external form, and peculiar to the Oolitic period. The annexed section (Fig. 246.) shows the curious form of the hollow part of each whorl, and also the perforation which passes up the middle of the columella. *N. Goodhallii* (Fig. 247.) is another English species of the same genus, from a formation which seems to form a passage from the Kimmeridge clay to the coral rag.*

A division of the oolite in the Alps, regarded by most geologists as coeval with the English coral

* Fitton, Geol. Trans., Second Series, vol. iv. pl. 23. fig. 12.

rag, has been often named "Calcaire à Dicerates," or "Diceras limestone," from its containing abundantly a bivalve shell (see Fig. 248.) of a genus allied to the *Chama*.

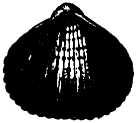
Among the characteristic shells of the Inferior Oolite, I may instance *Terebratula spinosa* (Fig. 251.), *Pholadomya fidicula* (Fig. 252), *Belemnites hastatus* (Fig. 253.), and *Terabratula digona* (Fig. 256.). The extinct genus *Pleurotomaria* is also a form very common in the Oolitic system. It resembles the *Trochus* in form, but is marked by a singular cleft (*a*, Fig. 250.) on the right side of the mouth.

Fig. 250.

Pleurotomaria ornata. Ferruginous oolite, Normandy. Inf. ool., England.

As illustrations of shells having a great vertical range, I may allude to *Trigonia gibbosa* (Fig. 245.), which abounds in the Portland stone of

Fig. 251.

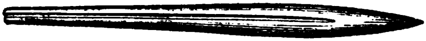


Terebratula spinosa. Inferior Oolite.

Fig. 252.

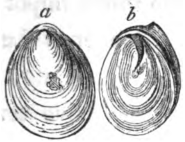
a. Pholadomya fidicula. ½ nat. size. Inf. Ool.
b. Heart-shaped anterior termination of the same.

Fig. 253.



Belemnites hastatus. Inferior Oolite.

Fig. 254.



Orbicula reflexa, Sow.
a. upper valve.
b. lower or attached valve, and showing part of the upper.

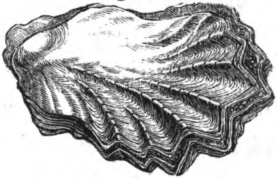
Fig. 255.

Ammonites striatulus, Sow.
½ nat. size.
Inferior Oolite and Lias.

Fig. 256.

Terebratula digona.
Lower Oolite, Bradford. Nat. size.

Fig. 257.



Ostrea Marshii. ½ nat. size.
Middle and Lower Oolite.

Wiltshire, and the Inferior Oolite of Yorkshire.* *Trigonia clavellata* also has the same range, and *T. costata* is common to the Upper, Middle, and Lower Oolite. Also *Ostrea Marshii* (Fig. 257.), common to the Cornbrash of Wilts and the Inferior Oolite of Yorkshire; and, lastly, *Orbicula reflexa* (Fig. 254.) and *Ammonites striatulus* (Fig. 255.), fossils common to the Inferior Oolite and Lias.

Such facts by no means invalidate the general rule, that certain fossils are good chronological

* See Williamson, Proceedings Geol. Soc., No. 47.

tests of geological periods; but they serve to caution us against attaching too much importance to single species, some of which may have a wider, others a more confined vertical range. We have before seen that, in the successive tertiary formations, there are species common to older and newer groups, yet these groups may be distinguishable from one another by a comparison of the whole assemblage of fossil shells proper to each.

Signs of neighbouring land and shoals.—The corals and shells above alluded to, and the fishes, crustacea, and other accompanying fossils, sufficiently attest the marine origin of the oolitic strata in general. Yet there are frequent signs of shallow water and of neighbouring land: and these are the more worthy of attention, as they by no means diminish as we proceed downwards to the inferior parts of the oolitic series. Had the bottom of the sea in Europe been unmoved during the entire Oolitic period, the first, or oldest beds of the oolite, must have been accumulated in the deepest water, the middle oolite in water of less depth, and the upper in the shallowest of all. The appearances about to be described militate against this conclusion. Fossil wood occurs in the Upper Oolite, showing that there were then lands from which plants were drifted into the sea. The Kimmeridge clay, a member of the Upper Oolite,

consists, in great part, of a bituminous shale, sometimes forming an impure coal several hundred feet in thickness. In some places in Wiltshire it much resembles peat; and the bituminous matter may have been, in part at least, derived from the decomposition of vegetables. But as impressions of plants are rare in these shales, which contain ammonites, oysters, and other marine shells, the bitumen may perhaps be of animal origin.

The celebrated lithographic stone of Solenhofen, in Bavaria, belongs to one of the upper divisions of the oolite, and affords a remarkable example of the variety of fossils which may be preserved under favourable circumstances, and what delicate impressions of the tender parts of certain animals and plants may be retained where the sediment is of extreme fineness. Although the number of testacea in this slate is small, and the plants few, and those all marine, Count Munster had determined no less than 237 species of fossils when I saw his collection in 1833; and among them no less than seven *species* of flying lizards, or pterodactyls, six saurians, three tortoises, sixty species of fish, forty-six of crustacea, and twenty-six of insects. These insects, among which is a libellula, or dragon-fly, must have been blown out to sea, probably from the same land to which the flying lizards, and other contemporaneous reptiles, resorted.

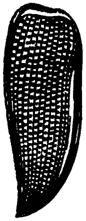
In the upper members of the *Lower Oolite* of England the ripple-mark is distinctly seen throughout a considerable thickness of thin fissile beds of a coarsely oolitic limestone. The rippled slabs are used for roofing, and have been traced over a broad band of country from Bradford, in Wilts, to Tetbury, in Gloucestershire. These calcareous slabs, or tile-stones, are separated from each other by thin seams of clay, which have been deposited upon them, and have taken their form, preserving the undulating ridges and furrows of the sand in such complete integrity, that the impressions of small footsteps, apparently of crabs, which walked over the soft wet sands, are still visible. In the same stone the claws of crabs, fragments of echini, broken shells, pieces of drift wood, and other signs of a neighbouring beach, are observed.

The slate of Stonesfield has lately been shown by Mr. Lonsdale to lie at the base of the Great Oolite.* It is a slightly oolitic shelly limestone, forming large spheroidal masses imbedded in sand, only six feet thick, but very rich in organic remains. It contains some pebbles of a rock very similar to itself, and with them the fossil remains of belemnites, trigoniæ, and other marine shells. Besides fragments of wood, which occur in all parts of the oolitic group, there are many

* Proceedings Geol. Soc. vol. i. p. 414.

impressions of ferns, cycadeæ, and other terrestrial

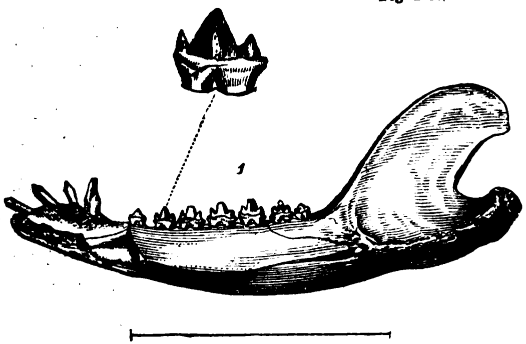
Fig. 258.



Elytron of Buprestis; Stonesfield.

plants. Several insects also, and, among the rest, the wing-covers of beetles, are perfectly preserved (see Fig. 258.), some of them approaching nearly to the genus *Buprestis.** The remains, also, of many genera of reptiles, such as *Plesiosaurus*, *Crocodile*, and *Pterodactyl*, have been discovered in the same limestone; and, what is still more remarkable, the jaws of at least two species of mammiferous quadrupeds, of the Marsupial order; one allied to the *Didelphys*, or opossum, and the other to the Myrmecobius of Australia (see Figures).

Fig. 259.



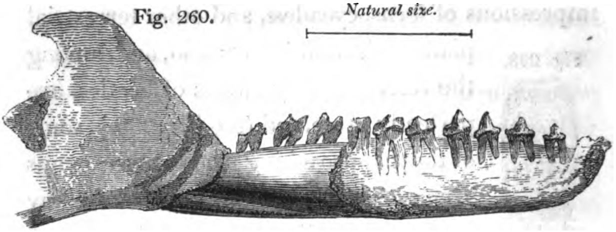
Natural size.

Phascolotherium Bucklandi, Owen. (Syn. *Didelphis Bucklandi*, Brod.)
Lower jaw, from Stonesfield.

1. The jaw magnified twice in length.
2. The second molar tooth magnified six times.

* See Buckland's Bridgewater Treatise.

Fig. 260.



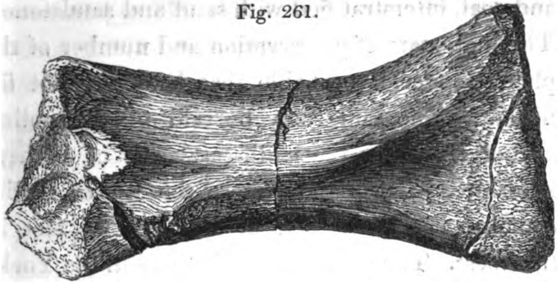
Thylacotherium Prevostii (Valenciennes). *Lower jaw, from the slate of Stonesfield, near Oxford.*

These fossils afford the only example yet known of terrestrial mammalia in rocks of a date anterior to the Eocene period.

This exception is the more deserving of notice, because even no cetacea have as yet been observed in any secondary strata, although certain bones, from the great oolite of Enstone, near Woodstock, in Oxfordshire, have been cited, on the authority of Cuvier, as referable to this class. Dr. Buckland, who has stated this in his late Bridgewater Treatise*, has had the kindness to send me the supposed ulna of a whale, in order that Mr. Owen might examine into its claims to be considered as cetaceous. It is the opinion of that eminent comparative anatomist that it cannot have belonged to the cetacea, because the ore-arm in these marine mammalia is invariably much flatter, and devoid of all muscular depressions and ridges, one of which is so prominent in the middle of this bone (see

* Vol. i. p.115.

Fig. 261.

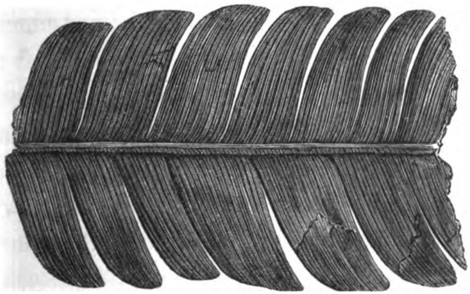


Bone of a reptile, formerly supposed to be the ulna of a Cetacean; from the Oolite of Enstone, near Woodstock.

Fig. 261.). In saurians, on the contrary, such ridges exist for the attachment of muscles; and to some animal of that class the bone is probably referable.

Oolite of Yorkshire and Scotland.—North of the Humber, in Yorkshire, the Lower Oolite assumes a form very different from that which distinguishes it in the south. It may there be called a coal formation, as it contains much vegetable matter,

Fig. 262.



Pterophyllum comptum. (Syn. *Cycadites comptus.*) Upper sandstone and shale, Gristhorpe, near Scarborough.

D 5

and coal, interstratified with sand and sandstones. The high state of preservation and number of the plants render it probable that land was not far distant. The same may be said of the oolitic coal of Brora, on the south-east coast of Sutherlandshire, in Scotland, where the Lower Oolite contains coal, one bed of which is 3½ feet in thickness. The plants resemble those in the Yorkshire oolite, and a great number of the associated marine shells and other fossils are the same*; but the mineral characters of the sandstone, shale, and calcareous grit differ considerably.

* Murchison, Geol. Trans., vol. ii. Second Series.

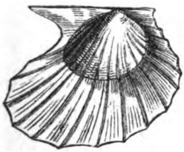
CHAPTER XXI.

OOLITE AND LIAS — *continued.*

Mineral character of Lias — Name of Gryphite limestone — Fossil fish — Ichthyodorulites — Reptiles of the Lias — Ichthyosaur and Plesiosaur — Newly-discovered marine Reptile of the Galapagos Islands—Sudden destruction and burial of fossil animals in Lias — Origin of the Oolite and Lias, and of alternating calcareous and argillaceous formations — Physical geography — Vales of clay — Hills and escarpments of limestone.

Lias. — The English provincial name of Lias has been very generally adopted for a formation of argillaceous limestone, marl, and clay, which forms the base of the Oolite, and is classed by many geologists as part of that group. They pass, indeed, into each other in some places, as near Bath, a sandy marl called the marlstone of the Lias being interposed, and partaking of the mineral characters of the upper lias and inferior oolite. These last-mentioned divisions have also some fossils in common, such as the *Avicula inæquivalvis* (Fig. 263.). Nevertheless the Lias may be traced throughout a great part of Europe as a separate and independent group, of considerable thickness, varying from 500 to 1000 feet, containing many peculiar fossils, and having a

Fig. 263.



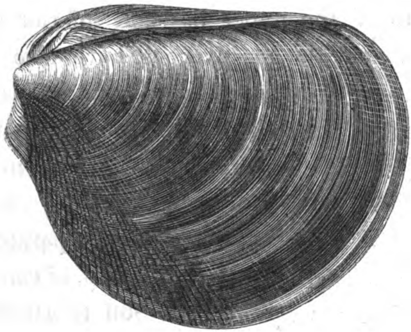
Avicula inæquivalvis, Sow.

very uniform lithological aspect. Although usually conformable to the oolite, it is sometimes, as in the Jura, unconformable. In the environs of Lons-le-Saulnier, for instance, the strata of lias are inclined at an angle of about 45°, while the incumbent oolitic marls are horizontal.

The peculiar aspect which is most characteristic of the Lias in England, France, and Germany, is an alternation of thin beds of limestone with a light brown weathered surface, separated by dark-coloured narrow argillaceous partings, so that the quarries of this rock, at a distance, assume a striped and riband-like appearance.*

Although the prevailing colour of the limestone of this formation is blue, yet some beds of the lower lias are of a yellowish white colour, and have been called white lias. In some parts of France, near the Vosges mountains, and in Lux-

Fig. 264.



Plagiostoma giganteum, Lias.

* Conyb. and Phil. p. 261.

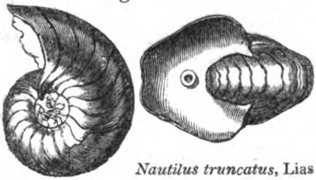
embourg, M. E. de Beaumont has shown that the lias containing *Gryphæa arcuata*, *Plagiostoma giganteum* (see Fig. 264.), and other characteristic fossils, becomes arenaceous; and around the Hartz, in Westphalia and Bavaria, the inferior parts of the lias are sandy, and sometimes afford a building stone.

The name of Gryphite limestone has sometimes been applied to the lias, in consequence of the great number of shells which it contains of a species of oyster, or *Gryphæa* (Fig. 265., see also Fig. 30. p. 62.). Many cephalopoda, also, such as *Ammonite*, *Belemnite*, and *Nautilus* (Fig. 266.), prove the marine origin of the formation.

Fig. 265.

Gryphæa incurva, Sow.
(*G. arcuata*, Lam.)

Fig. 266.

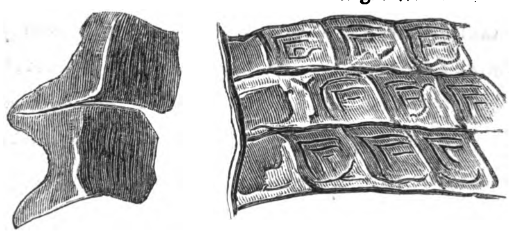


Nautilus truncatus, Lias.

The fossil fish resemble generically those of the oolite, belonging all, according to M. Agassiz, to extinct genera, and differing remarkably from the ichthyolites of the Cretaceous period. Among them is a species of *Lepidotus* (*L. gigas*, Agas.) (Fig. 267.), which is found in the lias of England, France, and Germany.* This genus was before

* Agasssiz, Pois. Fos., vol. ii. tab. 28, 29.

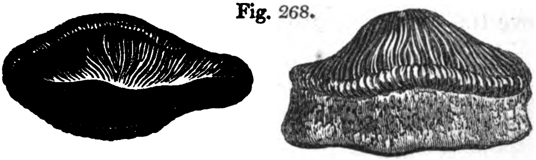
Fig. 267.



Scales of Lepidotus gigas, Agas.
a. two of the scales detached.

mentioned (Vol. I. p. 418.) as occurring in the Wealden, and is supposed to have frequented both rivers and coasts. The teeth of a species of *Acrodus*, also, are very abundant in the lias. (Fig. 268.)

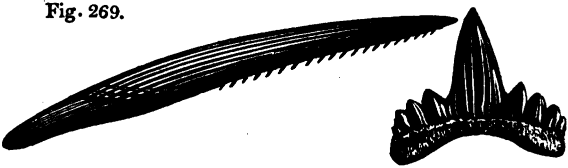
Fig. 268.



Acrodus nobilis, Agas. (tooth); commonly called fossil leach, Lias, Lyme Regis, and Germany.

But the remains of fish which have excited more attention than any others, are those large bony spines called *ichthyodorulites* (*a*, Fig. 269.),

Fig. 269.

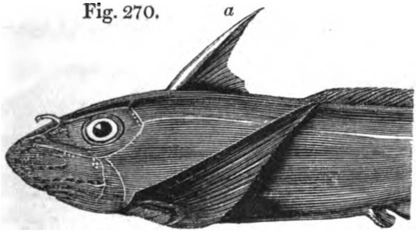


Hybodus reticulatus, Agas. Lias, Lyme Regis.

a. Part of fin, commonly called Ichthyodorulite.
b. Tooth.

which were once supposed by some naturalists to be jaws, and by others weapons, resembling those of the living *Balistes* and *Silurus*; but which M. Agassiz has shown to be neither the one nor the other. The spines, in the genera last mentioned, articulate with the backbone, whereas there are no signs of any such articulation in the ichthyodorulites. These last appear to have been bony spines which formed the anterior part of the dorsal fin, like that of the living genera *Cestracion* and *Chimæra* (see *a*, Fig. 270.). In both of these

Fig. 270.

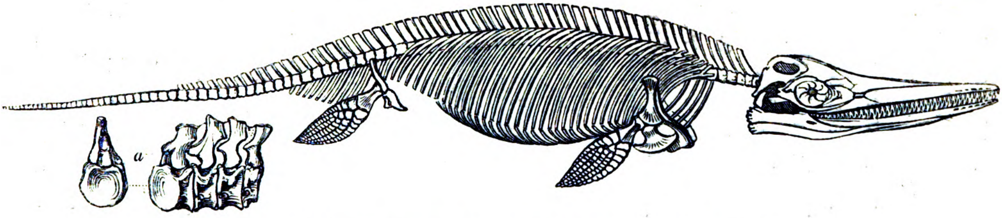


*Chimæra monstrosa.**
a. Spine forming anterior part of the dorsal fin.

genera, the posterior concave face is armed with small spines like that of the fossil *Hybodus* (Fig. 269.), one of the shark family found fossil at Lyme Regis. Such spines are simply imbedded in the flesh, and attached to strong muscles. "They serve," says Dr. Buckland, "as in the *Chimæra* (Fig. 270.), to raise and depress the fin, their action resembling that of a moveable mast,

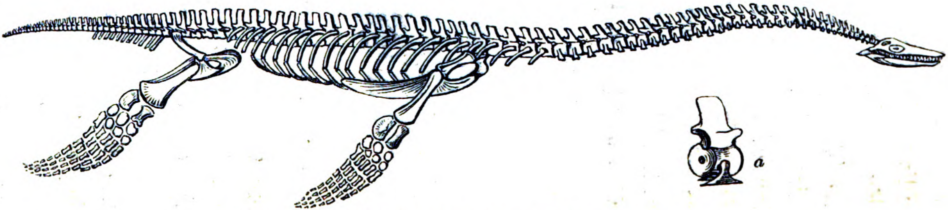
* Agassiz, Poissons Fossiles, vol. iii. tab. C. fig. 1.

Fig. 271.



Ichthyosaurus communis, restored by Conybeare and Cuvier.
a. costal vertebræ.

Fig. 272.



Plesiosaurus dolichodeirus, restored by Rev. W. D. Conybeare.
a. cervical vertebra.

raising and lowering backwards the sail of a barge." *

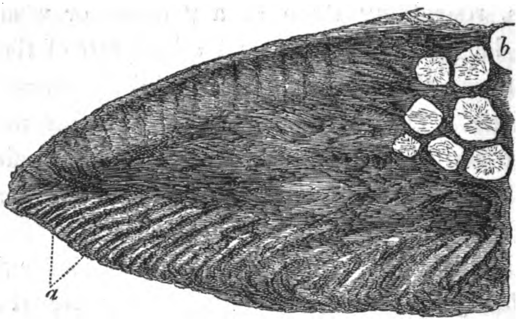
Reptiles of the Lias. — It is not, however, the fossil fish which form the most striking feature in the organic remains of the Lias; but the reptiles, which are extraordinary for their number, size, and structure. Among the most singular of these are several species of *Ichthyosaurus* and *Plesiosaurus*. The genus *Ichthyosaurus*, or fish-lizard, is not confined to this formation, but has been found in strata as high as the chalk-marl and gault of England, and as low as the muschelkalk of Germany, a formation which immediately succeeds the lias in the descending order.† It is evident from their fish-like vertebræ, their paddles, resembling those of a porpoise or whale, the length of their tail, and other parts of their structure, that the habits of the Ichthyosaurs were aquatic. Their jaws and teeth show that they were carnivorous; and the half-digested remains of fishes and reptiles, found within their skeletons, indicate the precise nature of their food.‡

Recently (1840) a specimen of the hinder fin of *Ichthyosaurus communis* has been discovered at Barrow-on-Soar, by Sir P. Egerton, which distinctly exhibits on its posterior margin the re-

* Bridgewater Treatise, p. 290.
† Ibid. p. 168.
‡ Ibid. p. 187.

mains of cartilaginous rays that bifurcate as they approach the edge, like those in the fin of a fish. (See *a*, Fig. 273.) It had previously been supposed, says Mr. Owen, that the locomotive organs of the Ichthyosaurus were enveloped, while living, in a smooth integument, like that of the turtle and porpoise, which has no other support than is afforded by the bones and ligaments within; but it now appears that the fin was much larger, expanding far beyond its osseous framework, and deviating widely in its fish-like rays from the ordinary reptilian type. In the annexed figure the posterior bones, or digital ossicles of the paddle, are seen near *b*; and beyond these is

Fig. 273.



Posterior part of hind fin of *Ichthyosaurus communis*.

the dark carbonized integument of the terminal half of the fin, the outline of which is beautifully defined.*

* Geol. Soc. Proceedings, No. 66, p. 157.

Mr. Conybeare was enabled, in 1824, after examining many skeletons nearly perfect, to give an ideal restoration of the osteology of this genus, and of that of the *Plesiosaurus*.* (See Figs. 271, 272.) The latter animal had an extremely long neck and small head, with teeth like those of the crocodile, and paddles analogous to those of the *Ichythyosaurus*, but larger. It is supposed to have lived in shallow seas and estuaries, and to have breathed air like the Ichthyosaur, and our modern cetacea.† Some of the reptiles above mentioned were of formidable dimensions. One specimen of *Ichthyosaurus platyodon*, from the lias at Lyme, now in the British Museum, must have belonged to an animal more than twenty-four feet in length; and another of the *Plesiosaurus*, in the same collection, is eleven feet long. The form of the *Ichthyosaurus* may have fitted it to cut through the waves like the porpoise; but it is supposed that the *Plesiosaurus*, at least the long-necked species (Fig. 272.), was better suited to fish in shallow creeks and bays defended from heavy breakers.

For the last twenty years, anatomists have agreed that these extinct saurians must have inhabited the sea; and it was argued that, as there

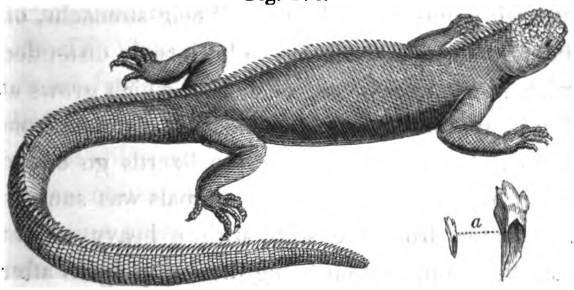
* Geol. Trans., Second Series, vol. i. pl. 49.

† Conybeare and De la Beche, Geol. Trans.; and Buckland, Bridgew. Treat., p. 203.

are now Chelonians, like the tortoise, living in fresh water, and others, as the turtle, frequenting the ocean, so there may have been formerly some saurians proper to salt, others to fresh water. The common crocodile of the Ganges is well known to frequent equally that river and the brackish and salt water near its mouth; and crocodiles are said in like manner to be abundant both in the rivers of the Isla de Pinos (or Isle of Pines), south of Cuba, and in the open sea round the coast. More recently a saurian has been discovered of aquatic habits and exclusively marine. This creature was found in the Galapagos islands, during the visit of H. M. S. Beagle to that archipelago, in 1835, and its habits were then observed by Mr. Darwin. The islands alluded to are situated under the equator, nearly 600 miles to the westward of the coast of South America. They are volcanic, some of them being 3000 or 4000 feet high; and one of them, Albemarle Island, 75 miles long. The climate is mild, very little rain falls; and, in the whole archipelago, there is only one rill of fresh water that reaches the coast. The soil is for the most part dry and harsh, and the vegetation scanty. The birds, reptiles, plants, and insects are, with very few exceptions, of species found nowhere else in the world, although all partake, in their general form, of an American character. Of the mammalia, says Mr. Darwin, one species alone appears

to be indigenous, namely, a large and peculiar kind of mouse; but the number of lizards, tortoises, and snakes is so great, that it may be called a land of reptiles. The variety, indeed, of species is small; but the individuals of each are in wonderful abundance. There is a turtle, a large tortoise (*Testudo Indicus*), four lizards, and about the same number of snakes, but no frogs or toads. Two of the lizards belong to the family *Iguanidæ* of Bell, and to a peculiar genus (*Amblyrhynchus*) established by that naturalist, and so named from their obtusely truncated head and short snout.* Of these lizards one is terrestrial in its habits, and burrows in the ground, swarming everywhere on the land, having a round tail, and a mouth somewhat resembling in form that of the tortoise. The other is aquatic, and has its tail flattened laterally for

Fig. 274.



Amblyrhynchus cristatus, Bell. Length varying from 3 to 4 ft. *The only existing marine lizard now known.*

a. Tooth, natural size and magnified.

* Αμβλυς, amblys, blunt; and ῥυγχος, rhynchus, snout.

swimming (see Fig. 274.) "This marine saurian," says Mr. Darwin, "is extremely common on all the islands throughout the archipelago. It lives exclusively on the rocky sea-beaches, and I never saw one even ten yards inshore. The usual length is about a yard, but there are some even four feet long. It is of a dirty black colour, sluggish in its movements on the land; but, when in the water, it swims with perfect ease and quickness by a serpentine movement of its body and flattened tail, the legs during this time being motionless, and closely collapsed on its sides. Their limbs and strong claws are admirably adapted for crawling over the rugged and fissured masses of lava which everywhere form the coast. In such situations a group of six or seven of these hideous reptiles may oftentimes be seen on the black rocks, a few feet above the surf, basking in the sun with outstretched legs. Their stomachs, on being opened, were found to be largely distended with minced sea-weed, of a kind which grows at the bottom of the sea at some little distance from the coast. To obtain this, the lizards go out to sea in shoals. One of these animals was sunk in salt water, from the ship, with a heavy weight attached to it, and on being drawn up again after an hour it was quite active and unharmed. It is not yet known by the inhabitants where this animal lays its eggs; a singular fact, considering

its abundance, and that the natives are well acquainted with the eggs of the terrestrial *Amblyrhynchus*, which is also herbivorous." *

In those deposits now forming by the sediment washed away from the wasting shores of the Galapagos islands the remains of saurians, both of the land and sea, as well as of chelonians and fish, may be mingled with marine shells without any bones of land quadrupeds or batrachian reptiles; yet even here we should expect the remains of marine mammalia to be imbedded in the new strata, for there are seals, besides several kinds of cetacea, on the Galapagian shores; and, in this respect, the parallel between the modern fauna, above described, and the ancient one of the lias, would not hold good.

Sudden destruction of saurians, &c. — It has been remarked, and truly, that many of the fish and saurians, found fossil in the lias, must have met with sudden death and immediate burial; and that the destructive operation, whatever may have been its nature, was often repeated.

" Sometimes," says Dr. Buckland, " scarcely a single bone or scale has been removed from the place it occupied during life; which could not have happened had the uncovered bodies of these saurians been left, even for a few hours, exposed

* Darwin's Journal, chap. xix. (For full title, see note, p. 168.)

to putrefaction, and to the attacks of fishes and other smaller animals at the bottom of the sea."* Not only are the skeletons of the Ichthyosaurs entire, but sometimes the contents of their stomachs still remain between their ribs, so that we can discover the particular species of fish on which they lived, and the form of their excrements. Not unfrequently there are layers of these coprolites at different depths in the lias, at a distance from any entire skeletons of the marine lizards from which they were derived; "as if," says Mr. De la Beche, "the muddy bottom of the sea received small sudden accessions of matter from time to time, covering up the coprolites and other exuviæ which had accumulated during the intervals."† It is further stated that, at Lyme Regis, those surfaces only of the coprolites which lay uppermost at the bottom of the sea have suffered partial decay, from the action of water before they were covered and protected by the muddy sediment that has afterwards permanently enveloped them.‡

Numerous specimens of the pen-and-ink fish (*Sepia loligo*, Lin.; *Loligo vulgaris*, Lam.) have also been met with in the lias at Lyme, with the ink-bags still distended, containing the ink in a dried state, chiefly composed of carbon, and but

* Bridgew. Treat., p. 125.
† Geological Researches, p. 334.
‡ Buckland, Bridgew. Treat., p. 307.

slightly impregnated with carbonate
These cephalopoda, therefore, must, li
rians, have been soon buried in sedim
long exposed after death, the membrane contain-ing the ink would have decayed.*

As we know that river fish are sometimes stifled, even in their own element, by muddy water during floods, it cannot be doubted that the periodical discharge of large bodies of turbid fresh water into the sea may be still more fatal to marine tribes. In the Principles of Geology, I have shown that large quantities of mud and drowned animals have been swept down into the sea by rivers during earthquakes, as in Java, in 1699; and that undescribable multitudes of dead fishes have been seen floating on the sea after a discharge of noxious vapours during similar convulsions.† But, in the intervals between such catastrophes, strata may have accumulated slowly in the sea of the lias, some being formed chiefly of one description of shell, such as ammonites, others of gryphites.

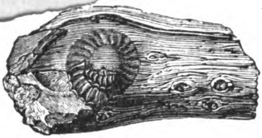
Fossil plants. — Among the vegetable remains of the Lias, several species of Zamia have been found at Lyme Regis, and the remains of coniferous plants at Whitby. Fragments of wood are

* Buckland, Bridgew. Treat., p. 307.

† See Principles, *Index*, Lancerote, Graham Island, Calabria.

and often converted into limestone. of this wood, though now petrified,

275.



was soft when it first lay at the bottom of the sea, is shown by a specimen now in the museum of the Geological Society (see Fig. 275.), which has the form of an *ammonite* indented on its surface.

Origin of the Ooolite and Lias. — If we now endeavour to restore, in imagination, the ancient condition of the European area at the period of the Oolite and Lias, we must conceive a sea in which the growth of coral reefs and shelly limestones, after proceeding without interruption for ages, was liable to be stopped suddenly by the deposition of clayey sediment. Then, again, the argillaceous matter, devoid of corals, was deposited for ages, and attained a thickness of hundreds of feet, until another period arrived when the same space was again occupied by calcareous sand, or solid rocks of shell and coral, to be again succeeded by the recurrence of another period of argillaceous deposition. Mr. Conybeare has remarked of the entire group of Oolite and Lias, that it consists of repeated alternations of clay, sandstone, and limestone, following each other in the same order. Thus the clays of the lias are followed by the sands of the inferior oolite, and

these again by shelly and coralline limestone (Bath oolite, &c.); so, in the middle oolite, the Oxford clay is followed by calcareous grit and "coral rag;" lastly, in the upper oolite the Kimmeridge clay is followed by the Portland sand and limestone.* The clay beds, however, as Mr. De la Beche remarks, can be followed over larger areas than the sands or sandstones.† It should also be remembered that while the oolitic system becomes arenaceous, and resembles a coal-field in Yorkshire, it assumes, in the Alps, an almost purely calcareous form, the sands and clays being omitted; and even in the intervening tracts, it is more complicated and variable than appears in ordinary descriptions. Nevertheless, some of the clays and intervening limestones do, in reality, retain a pretty uniform character, for distances of from 400 to 600 miles from east to west and north to south.

According to M. Thirria, the entire oolitic group in the department of the Haute Saône, in France, may be equal in thickness to that of England; but the importance of the argillaceous divisions is in the inverse ratio to that which they exhibit in England, where they are about equal to twice the thickness of the limestones, whereas, in the part of France alluded to, they reach only

* Con. and Phil., p. 166. † Geol. Researches, p. 337.

about a third of that thickness.* In the Jura the clays are still thinner; and in the Alps they thin out and almost vanish.

In order to account for such a succession of events, we may imagine, first, the bed of the ocean to be the receptacle for ages of fine argillaceous sediment, brought by oceanic currents, which may have communicated with rivers, or with part of the sea near a wasting coast. This mud ceases, at length, to be conveyed to the same region, either because the land which had previously suffered denudation is depressed and submerged, or because the current is deflected in another direction by the altered shape of the bed of the ocean and neighbouring dry land. By such changes the water becomes once more clear and fit for the growth of stony zoophytes. Calcareous sand is then formed from comminuted shell and coral, or, in some cases, arenaceous matter replaces the clay; because it commonly happens that the finer sediment, being first drifted farthest from coasts, is subsequently overspread by coarse sand, after the sea has grown shallower, or when the land, increasing in extent, has approached nearer to the spots first occupied by fine mud.

In order to account for another great formation, like the Oxford clay, again covering one of

* Burat's D'Aubuisson, tom. ii. p. 456.

coral limestone, we must suppose a sinking down like that which is now taking place in some existing regions of coral between Australia and South America.* The occurrence of subsidences, on so vast a scale, may again have caused the bed of the ocean and the adjoining land, throughout great parts of the European area, to assume a shape favourable to the deposition of another set of clayey strata; and this change may have been succeeded by a series of events analogous to that already explained, and these again by a third series in similar order. Both the ascending and descending movements may have been extremely slow, like those now going on in the Pacific; and the growth of every stratum of coral, a few feet in thickness, may have required centuries for its completion, during which certain species of organic beings may have disappeared from the earth, and others have been introduced in their place; so that, in each set of strata, from the Upper Oolite to the Lias, some peculiar and characteristic fossils were imbedded.

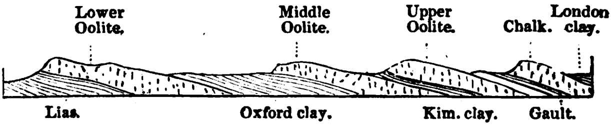
Physical geography. — The alternation, on so large a scale, of distinct formations of clay and limestone, has given rise to some marked features in the physical outline of parts of England and France. Wide valleys can usually be traced

* See Darwin's Journal, chap. xxii.

throughout the long bands of country where the argillaceous strata crop-out; and between these valleys the limestones are observed, composing ranges of hills, or more elevated grounds. These ranges terminate abruptly on the side on which the several clays crop-out from beneath the calcareous strata.

The annexed diagram will give the reader an idea of the configuration of the surface now alluded to, such as may be seen in passing from London to Cheltenham, or in other parallel lines, from east to west, in the southern part of England. It has been necessary, however, in this

Fig. 276.



drawing, greatly to exaggerate the inclination of the beds, and the height of the several formations, as compared to their horizontal extent. It will be remarked, that the lines of cliff, or escarpment, face towards the west in the great calcareous eminences formed by the Chalk and the Upper, Middle, and Lower Oolites; and at the base of each we have respectively the Gault, Kimmeridge clay, Oxford clay, and Lias. This last forms, generally, a broad vale at the foot of the escarp-

ment of Inferior Oolite; but a considerable portion of that escarpment is sometimes occupied by lias. The external outline of the country which the geologist observes in travelling eastward from Paris to Metz is precisely analogous, and is caused by a similar succession of rocks intervening between the tertiary strata and the Lias; with this difference, however, that the escarpments of Chalk, Upper, Middle, and Lower Oolites, face towards the east instead of the west.

The Chalk crops-out from beneath the tertiary sands and clays of the Paris basin, near Epernay, and the Gault from beneath the Chalk and Upper Green-sand at Clermont en Argonne; and passing from this place by Verdun and Etain to Metz, we find two limestone ranges, with intervening vales of clay, precisely resembling those of southern and central England, until we reach the great plain of Lias at the base of the Inferior Oolite at Metz.

It is evident, therefore, that the denuding causes have acted similarly over an area several hundred miles in diameter, sweeping away the softer clays more extensively than the limestones, and undermining these last so as to cause them to form steep cliffs wherever the harder calcareous rock was based upon a more yielding and destructible clay. This denudation probably occurred while the land was slowly rising out of the sea.*

* See Chapters 6. and 19.

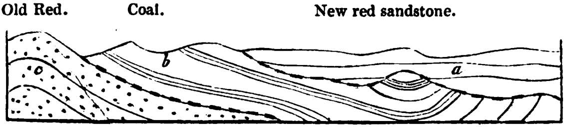
CHAPTER XXII.

NEW RED SANDSTONE GROUP.

Distinction between New and Old Red sandstone — Between Upper and Lower New Red — Bone-bed of Axmouth and Aust — Red sandstone of Warwickshire and Cheshire — Footsteps of *Chirotherium* in England and Germany — Osteology of the *Labyrinthodon* — Identification of this Batrachian with the Chirotherium — Gypsum and rock-salt in Upper New Red — Trias of the Germans — Its fossils — Muschelkalk — Lower New Red and Magnesian limestone — Zechstein in Germany of the same age — Points of analogy between the organic remains of the Magnesian limestone and Carboniferous strata — Heterocercal fish — Saurians of the Lower New Red — Origin of red sandstone and red marl.

Between the Lias and the Coal, or Carboniferous group, there is interposed, in the midland and western counties of England, a great series of red marls and sandstones, to which the name of the New Red Sandstone formation was given, to distinguish it from other marls and sandstones called the "Old Red" (*c*, Fig. 277.), often identical in mineral character, which lie immediately beneath the coal, *b*.

Fig. 277.



In some parts of the south-west of England, the entire "New Red" group consists exclusively of red loam, clay, and sandstone, devoid of fossils, strongly contrasted in colour, and the general absence of calcareous matter, with the Oolitic rocks and Lias before described. But when we extend our observations over England and other countries, we no longer find this simplicity of structure; but perceive that the strata between the Lias and the Coal are divisible into two very distinct systems, which will be understood from the accompanying Table, and the description which follows.

NEW RED SANDSTONE GROUP.

*Poikilitic group of Conybeare and Buckland.**

		Synonyms. German.	Synonyms. French.
1. Upper new red.	*a.* Saliferous marls and sandstone	Keuper	Marnes irisées.
	b. (wanting in England)	Muschelkalk	Muschelkalk, ou calcaire coquillier.
	c. Sandstone and quartzose conglomerate	Bunter sandstein	Grès bigarré.
2. Lower new red.	*d.* Magnesian limestone (dolomitic conglomerate)	Zechstein, and Kupferschiefer	Zechstein, ou schiste cuivreux — et Calcaire Magnésien.
	e. Lower New Red sandstone.	Rothliegendes	Grès des Vosges, couches inférieures?

* From ποικίλος, Poikilos *variegated* (see Buckland, Bridg. Treat., vol. ii. p. 38.), because some of the most characteristic strata of this group were called *variegated* by Werner, from their exhibiting spots and streaks of light blue, green, and buff colour, in a red base.

UPPER NEW RED SANDSTONE.

(*Trias of the Germans.*)

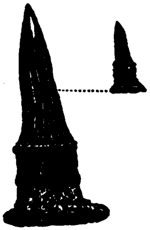
The Lias is succeeded in England by conformable strata of red and green marl, or clay. There intervenes, however, both in the neighbourhood of Axmouth, in Devonshire, and in the cliffs of Westbury and Aust, in Gloucestershire, on the banks of the Severn, a dark-coloured stratum, well known by the name of the "bone-bed." It abounds in the remains of saurians and fish, and was formerly classed as the lowest bed of the Lias; but Sir P. Egerton has lately shown that it should be referred to the Upper New Red Sandstone, for it contains an assemblage of fossil fish which are either peculiar to this stratum, or belong to species well known in the Continental Muschelkalk. These fish belong to the genera *Acrodus*, *Hybodus*, *Gyrolepis*, and *Saurichthys*.

Among those common to the English bone-bed and the Muschelkalk of Germany are *Hybodus plicatilis* (Fig. 278.), *Saurichthys apicalis* (Fig. 279.),

Fig. 278.

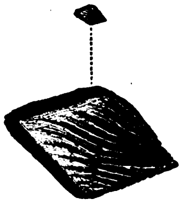
Hybodus plicatilis. Teeth. Bone-bed, Aust and Axmouth.

Fig. 279.



Saurichthys apicalis.
Tooth ; nat. size, and magnified.
Axmouth.

Fig. 280.



Gyrolepis tenuistriatus.
Scale, nat. size ; and magnified.
Axmouth.

Gyrolepis tenuistriatus (Fig. 280.), and *G. Albertii.* Remains of saurians have also been found in the bone-bed, and plates of an *Encrinus.*

The strata of red and green marl, which follow the bone-bed in the descending order at Axmouth and Aust, are destitute of organic remains; as is the case, for the most part, in the corresponding beds in almost every part of England. But fossils have lately been found at a few localities in sandstones of this formation, and among them the bivalve shell called *Posidonia minuta*, Goldf. (Fig. 289. p. 93.), as in Worcestershire and Warwickshire. Impressions, also, of the footsteps of several animals have been detected in the county last named, and in Cheshire; among which some of the most remarkable occur a few miles from Liverpool, in the sandstone of Storeton Hill, on the west side of the Mersey. They bear a close resemblance to the tracks previously observed in

a member of the Upper New Red Sandstone, at the village of Hesseberg, near Hildburghausen, in Saxony, which had been for many years referred to a large unknown quadruped, provisionally named *Chirotherium* by Professor Kaup, because the marks both of the fore and hind feet resembled impressions made by a human hand. (See Fig. 281.) The foot-marks at Hesseberg are partly concave and partly in relief; the former, or the depressions, are upon the upper surface of the sandstone slabs, but those in relief are only upon the lower surfaces, being in fact natural casts, formed in the subjacent foot-prints as in moulds. The larger impressions, which seem to be those of the hind foot, are generally eight inches in length, and five in width, and one was twelve inches long. Near each large footstep, and at a regular distance (about an inch and a half) before it, a smaller

Fig. 281.

Single footstep of Chirotherium. Bunter Sandstein, Saxony; one eighth of nat. size.

Fig. 282.

Line of footsteps on slab of sandstone. Hildburghausen, in Saxony.

print of a fore foot, four inches long and three inches wide, occurs. The footsteps follow each

other in pairs, each pair in the same line, at intervals of 14 inches from pair to pair. The large as well as the small steps show the great toes alternately on the right and left side; each step makes the print of five toes, the first or great toe being bent inwards like a thumb. Though the fore and hind foot differ so much in size, they are nearly similar in form.

The description here given of fossil footsteps observed in Germany, answers with singular accuracy to those afterwards found in a formation of the same age in England. They occur at Storeton on the Mersey, on five thin beds of clay, superimposed one upon the other in the same quarry, and separated by beds of sandstone. On the lower surface of the sandstone strata the solid casts of each impression are salient, in high relief, and afford models of the feet, toes, and claws of the animals which trod on the clay.

As neither in Germany nor in England any bones or teeth are met with in the same identical strata as the footsteps, anatomists indulged, for several years, in various conjectures respecting the mysterious animals from which they might have been derived. Professor Kaup suggested that the unknown quadruped might have been allied to the *Marsupialia*; for in the kangaroo the first toe of the fore foot is in a similar manner set obliquely to the others, like

a thumb, and the disproportion between the fore and hind feet is also very great. But M. Link conceived that some of the four species of animals of which the tracks had been found in Saxony might have been gigantic *Batrachians*; and Dr. Buckland designated some of the footsteps as those of a small web-footed animal, probably crocodilean.

In the course of these discussions several naturalists of Liverpool, in their report on the Storeton quarries, declared their opinion that each of the thin seams of clay in which the sandstone casts were moulded had formed successively a surface above water, over which the *Chirotherium* and other animals walked, leaving impressions of their footsteps, and that each layer had been afterwards submerged by a sinking down of the surface, so that a new beach was formed at low water above the former, on which other tracks were then made. In the same manner, the repeated occurrence of ripple-marks at various heights and depths in the red sandstone of Cheshire had been explained. Several geologists had also remarked that impressions of such depth and clearness could only have been made by animals walking on dry land, as their weight could not have been sufficient to cause them to sink so deeply in yielding clay under water.

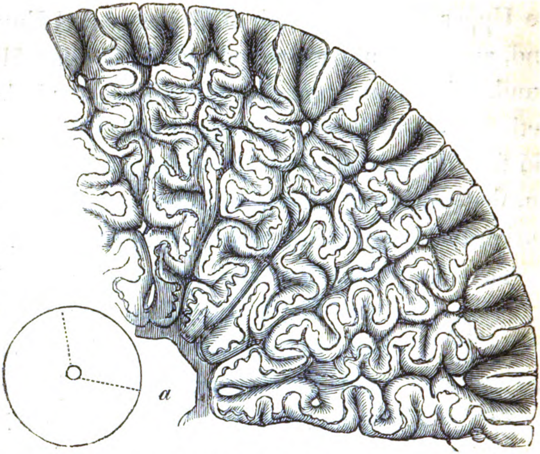
When the inquiry had been brought to this

point the reptilian remains hitherto discovered in the Upper New Red, both of Germany and England, were carefully examined by Mr. Owen. He found, after a microscopic investigation of the teeth from the German sandstone called Keuper, and from the sandstone of Warwick and Leamington, that neither of them could be referred to true saurians, although they had been named *Mastodonsaurus* and *Phytosaurus* by Jäger (Fig. 283.). It appeared that they were of the *Batrachian* order, and attested the former existence of frogs of gigantic dimensions in comparison with any now living. Both the Continental and English fossil teeth exhibited a most complicated texture, differing from that previously observed in any reptile, whether recent or extinct, but most nearly analogous to the *Ichthyosaurus*. A section of one of these teeth exhibits a series of irregular folds, resembling the labyrinthic windings of the surface of the brain; and from this character Mr. Owen has proposed the name of *Labyrinthodon* for the new genus. By his permission, the annexed representation of one is given from his "Odontography," plate 64. A. (Fig. 284.). The entire length of the tooth is supposed to have been about three inches and a half, and the breadth at the base one inch and a half.

Fig. 283.

Tooth of *Labyrinthodon*; nat. size. Warwick sandstone.

Fig. 284.



Transverse section of tooth of *Labyrinthodon Jaegeri*, Owen (*Mastodonsaurus Jaegeri*, Meyer.) Nat. size, and a segment magnified.

a. Pulp cavity, from which the processes of pulp and dentine radiate.

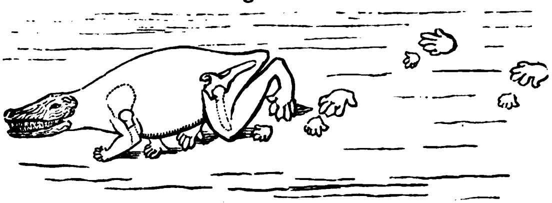
When Mr. Owen had satisfied himself, from an inspection of the cranium, jaws, and teeth, that a gigantic *Batrachian* had existed at the period of the Upper New Red Sandstone, he soon found, from the examination of various bones derived from the same formation, that he could define three species of *Labyrinthodon*, and that in this genus the hind extremities were much larger than the anterior extremities. This circumstance, coupled with the fact of the *Labyrinthodon* having existed at the period when the *Chirotherian* footsteps were made, was the first step towards the identification of those tracks with the newly dis-

covered *Batrachian.* It was at the same time observed that the foot-marks of *Chirotherium* were more like those of toads than of any other living animal; and, lastly, that the size of the three species of *Labyrinthodon* corresponded with the size of three different kinds of foot-prints which had already been supposed to belong to three distinct *Chirotheria.* It was, moreover, inferred with confidence that the *Labyrinthodon* was an air-breathing reptile, from the structure of the nasal cavity, in which the posterior outlets were at the back part of the mouth, instead of being directly under the anterior or external nostrils. It must have respired air after the manner of saurians, and may therefore have imprinted on the shore those footsteps, which, as we have seen, could not have originated from an animal walking under water.

It is true that the structure of the foot is still wanting, and that a more connected and complete skeleton is required for demonstration; but the circumstantial evidence above stated is strong enough to produce the conviction that the *Chirotherium* and *Labyrinthodon* are one and the same.

In order to show the manner in which one of these formidable *Batrachians* may have impressed the mark of its feet upon the shore, Mr. Owen has attempted a restoration, of which a greatly reduced copy is annexed.

Fig. 285.



Labyrinthodon pachygnathus, Owen.

The only bones of this species at present known are those of the head, the pelvis, and part of the scapula, which are shown by stronger lines in the above figure. There is reason for believing that the head was not smooth externally, but protected by bony scutella.

The term "Saliferous Marl and Sandstone" has been applied to the Upper New Red System, because it is in this group that rock-salt and salt springs occur in Cheshire and other parts of England, where the alternating beds of red and green marl, gypsum, and rock-salt sometimes exceed 600 feet in thickness. The gypsum is generally fibrous, and intercalated very irregularly between the laminated argillaceous beds. The rock-salt is sometimes clear and white, but is usually reddened by the argillaceous sediment with which it is associated. At Northwich, in Cheshire, are two beds of solid rock-salt, which are, together, not less than 60 feet in thickness. The origin of these vast deposits of muriate of

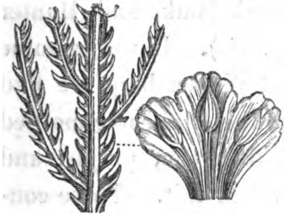
soda is still one of the most obscure problems in theoretical geology.

In Germany, the Upper New Red Sandstone is far more fully developed than in England, and has been called the Trias, or triple group; comprising the Keuper, Muschelkalk, and Bunter Sandstein (see Table, p. 81.). If we examine this group in Bavaria and Wurtemberg, we find that first in order beneath the Lias come mottled marls and sandstones, red, green, purple, and white, containing gypsum and salt. These constitute the Keuper; then follows the Muschelkalk, or shelly-limestone, rich in organic remains; and then another set of marls and sandstones, much resembling the first or Keuper division, and called "Bunter," from their variegated and spotted character. That these three formations belong to one great period, appears from the fact that Count Munster has obtained many of the same plants from the Keuper and Bunter Sandstein; and M. Agassiz the same species of fish from both of them, and from the interposed Muschelkalk. It is also worthy of remark, that the strata of the Muschelkalk alternate with those of the Keuper and Bunter Sandstein at their junction.

The fossil Flora, above alluded to, consists of *Cycadeæ* and several genera of ferns; also extinct *Coniferæ* of the genus *Voltzia* (Ad. Brongniart)

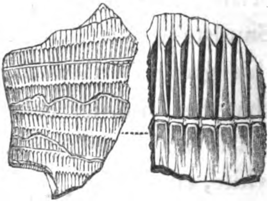
peculiar to this period, in which even the fructification has been preserved (Fig. 286.), and a gigantic species of *Equisetum* (Fig. 287.), which is not uncommon in the Keuper sandstone.

Fig. 286.



Voltzia brevifolia, and portion magnified to show fructification; Sulzbad. Keuper and Bunter Sandstein.

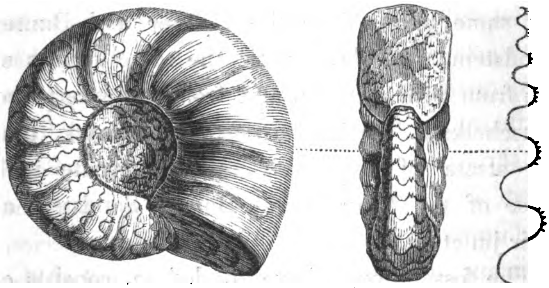
Fig. 287.



Equisetum columnare; fragment of stem, and small portion of same magnified. Keuper.

Among the shells, some of the Cephalopoda are peculiar; as, for example, that form of *Ammonite* which is called *Ceratite* by De Haan, in which the descending lobes (see *a*, *b*, *c*, Fig. 288.) ter-

Fig. 288. *a* *b* *c*



Ammonites nodosus. Muschelkalk.

a. Side view. *b*. Front view.
c. Partially denticulated outline of the septa dividing the chambers.

minate in a few small denticulations pointing inwards. Among the bivalve shells, the *Posidonia minuta*, Goldf. (*Posidonomya minuta*, Bronn), Fig. 289., is abundant, ranging from the Keuper to the Bunter Sandstein; and *Avicula socialis* (Fig. 290.), having a similar range, but most charac-

Fig. 289.

Posidonia minuta, Goldf. (*Posidonomya minuta*, Bronn.)

a Fig. 290. *b*

a. Avicula socialis. *b. Side view of same.*
Characteristic of the Muschelkalk.

teristic of the Muschelkalk in Germany, France, and Poland.

There are also some encrinites in the Muschelkalk, and some teeth of cartilaginous fish; a few decapod crustacea; and large extinct reptiles of peculiar forms, such as the *Labyrinthodon* before mentioned, to which the fossil footsteps of the Bunter Sandstein of Hildburghausen seem to be referable. Upon the whole, Professor Bronn has enumerated, in his "Lethæa Geognostica," no less than forty-seven genera of fossil remains from the three divisions of the "Upper New Red" system in Germany; and these fossils are the more important, as being all distinct in species, and many of them in genera, from those of the incumbent Lias, or more ancient Magnesian limestone.

It would scarcely be possible to draw a distinct line of demarcation between the Keuper and Bunter Sandstein, even in Germany, where they are not barren of fossils, if the Muschelkalk did not intervene between them. In England, therefore, where this calcareous formation is wanting, and where there are scarcely any organic remains in the Upper New Red marl and sandstone, we cannot feel assured that the divisions *a.* and *c.* of our Table, p. 81., do really coincide with the German Keuper and Bunter Sandstein. But it has been found convenient in the counties of Salop, Stafford, and Worcester, to divide the saliferous marls from the inferior quartzose conglomerate in the manner above indicated.

LOWER NEW RED SANDSTONE AND MAGNESIAN LIMESTONE GROUP.

We now come to the Magnesian Limestone or Lower New Red Sandstone group, the position of which can be best determined in Germany, because it is there interposed between the Coal and Bunter Sandstein, or oldest part of the "Upper New Red," above described. In the south-west of England the New Red sandstone formation is unconformable to the Coal (see Fig. 277.); but in the north-east of England Professor Sedgwick has shown that the same series is conformable to the carboniferous strata, and passes

into them. In other words, the movements which deranged "the Coal" in the south-west, previously to the origin of the New Red sandstone, did not extend towards Durham and the more northern counties.

Near Bristol, in Somersetshire, and in other counties bordering the Severn, the unconformable beds of the Lower New Red, resting immediately upon the Coal, consist of a conglomerate called "dolomitic," because the pebbles of older rocks are cemented together by a red or yellow base of dolomite or magnesian limestone. This conglomerate or breccia, for the imbedded fragments are sometimes angular, occurs in patches over the whole of the downs near Bristol, filling up the hollows and irregularities in the mountain limestone, and being principally composed at every spot of the debris of those rocks on which it immediately rests. At one point we find pieces of coal shale, in another of mountain limestone of large size, and exhibiting its peculiar shells and zoophytes. Fractured bones also of saurians and some teeth are dispersed throughout the breccia; and they all belong, as will be seen in the sequel, to genera of a peculiar type. (See p. 100.)

In the north-east of England the dolomitic conglomerate is represented by a yellow limestone, generally called the Magnesian Limestone, which passes upwards into marl slate, and downwards

into red marl and gypsum. In the intermediate counties of Worcester, Stafford, and Salop, are conglomerates referred to the same age, but which are calcareous, with scarcely any magnesia. Between these conglomerates and the Coal is a great formation, called the Lower New Red Sandstone (see Table, p. 81.), composed of sandstones, red shales, and marls, occasionally spotted green.*

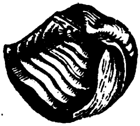
The country of Mansfeld, in Thuringia, may be called the classic ground of the Lower New Red, or Magnesian Limestone formation, on the Continent. It has there been long celebrated, because one of its members, a slaty marlstone, is richly impregnated with copper pyrites, for which it is extensively worked. The formation in that country is composed of an upper calcareous division, called the Zechstein, and a lower red quartzose formation of sandstone and conglomerate, called the Rothliegendes. The upper of these systems is very complex, consisting of marl, limestone, copper-slate, magnesian limestone, gypsum, and rock-salt, in which numerous fossils occur, bearing a striking generic resemblance to those of our English Magnesian Limestone. The Lower system, or Rothliegendes, is interposed between the Zechstein and the Coal; and is supposed to

* Murchison, Silurian System, p. 54.

correspond with the Lower New Red Sandstone above mentioned, as occupying a similar place in England between our Magnesian Limestone and Coal. Its local name of Rothliegendes, *red-lyer*, or "Roth-todt-liegendes," *red-dead-lyer*, was given by the workmen in the German mines from its red colour, and because the copper has *died out* when they reach this rock, which is not metalliferous. It is, in fact, a great deposit of red sandstone and conglomerate, with associated porphyry, basaltic trap, and amygdaloid.

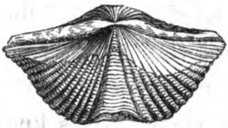
When we consider the fossils of the Magnesian Limestone in England, or corresponding Zechstein in Germany, we find that they approach much nearer in their character to the organic remains of the older Carboniferous group than to those of the Upper New Red. Thus, for example, the two genera of shells, *Producta* and *Spirifer*,

Fig. 291.



Producta calva, Sow.
(*Leptæna*, Dalman.)
Magnesian Limestone.

Fig. 292.

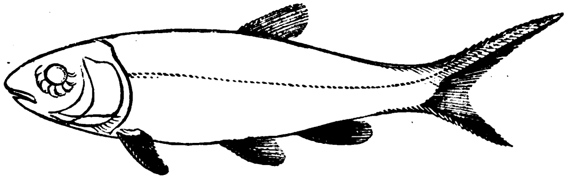


Spirifer undulatus, Sow.
Magnesian Limestone.

of the family Brachiopoda, are common to the Magnesian Limestone, Coal, and Primary fossiliferous strata; but the former has never been met with in any rock above the Magnesian limestone,

and the *Spirifer* very rarely, the only instance known to me being *S. Walcottii* of the Lias. There are certain fish also found, both in England and Germany, in the Lower New Red system, which occur in the Carboniferous strata; but in no formation higher in the series than the Magnesian limestone, not even in the Muschelkalk.

Fig. 293.



Restored outline of a fish of the genus Palæoniscus, Agass.*
Magnesian Limestone.

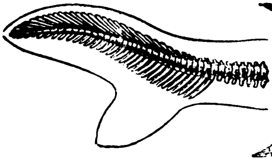
The genus *Palæoniscus*, Agas. (*Palæothrissum*, Blain.) is the most striking example, as three species have been found in England in marl slate, immediately below the Magnesian limestone, and three other different, but nearly allied species, in the slate of the Zechstein of Germany†; and of this genus, which has never yet been met with in rocks of more modern date, there are eight or ten species known in the subjacent Coal. The scales in the species last mentioned are generally smooth, while those in the Magnesian limestone are striated.

* Poissons Fossiles, vol. i. tab. A. fig. 4.
† Sedgwick, Geol. Trans., Second Series, vol. iii. p. 117.

At Tyrone, in Ireland, about three miles east of Dungannon, a deposit of New Red Sandstone occurs, overlying Coal, in which the surface of the beds are often ripple-marked, and in which a small species of *Palæoniscus* (*P. catopterus*, Agas.) occurs in abundance. A slab of this red sandstone now in the museum of the Geological Society of London exhibits, on a surface not exceeding two feet square, more than 250 entire fishes.

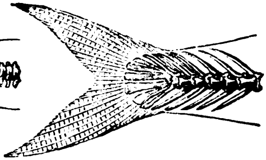
The *Palæoniscus* belongs to that division of fishes which M. Agassiz has called "Heterocercal," which have their tails unequally bilobate, like the recent shark and sturgeon, and the vertebral column running along the upper caudal lobe. (See Fig. 294.) The "Homocercal" fish,

Fig. 294.



Shark.
Heterocercal.

Fig. 295.



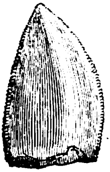
Shad. (*Clupea*, Herring tribe.)
Homocercal.

which comprise almost all the 8000 species at present known in the living creation, have the tail-fin either single or equally divided; and the vertebral column stops short, and is not prolonged into either lobe. (See Fig. 295.)

Now it is a singular fact, first pointed out by Agassiz, that the heterocercal form, which is confined to a small number of genera in the existing creation, is universal in the Magnesian limestone, and all the more ancient formations. It characterizes the earlier periods of the earth's history, when the organization of fishes made a greater approach to that of saurian reptiles than at later epochs. In all the strata above the Magnesian limestone the homocercal tail predominates.

The saurians of the period now under consideration (the most ancient examples of fossil reptiles yet known), are all distinguished by having the teeth implanted deeply in the jaw-bone, and in distinct sockets. In the dolomitic conglomerate near Bristol the remains of species of two

Fig. 296.



Tooth of *Palæosaurus platyodon*, nat. size.

Fig. 297.

Tooth of *Thecodontosaurus*, 3 times magnified.

distinct genera have been found, called *Thecodontosaurus* and *Palæosaurus* by Dr. Riley and Mr.

Stutchbury *; the teeth of which are conical, compressed, and with finely serrated edges.

In the Zechstein of Germany, a rock, as we have seen, of corresponding age, a small saurian reptile, allied, like the former, to the Monitor, has long been known, and has been called *Protorosaurus.*

The resemblance before alluded to between the fossils of the Lower New Red system and those of the Coal is not confined to the mollusca and fish, but extends to the Crinoidea, or Stone-lilies. It has even been supposed that some of the species were the same. Thus some specimens, found by Professor Sedgwick in the Magnesian limestone of Durham, were identified by Mr. Miller with *Cyathocrinites planus* (Fig. 320.) of the Mountain limestone of Bristol †; but Mr. Phillips, after comparing these fossils, believes them to be different, those of the Magnesian limestone belonging to *Encrinites moniliformis.*

Origin of the New Red Sandstone group. — The red sandstone and red marl, which, in point of thickness, form the most considerable part both of the upper and lower New Red formation in

* See paper by Messrs. Riley and Stutchbury, Geol. Trans., Second Series, vol. v. p. 349., plate 29., figures 2. and 5.

† Sedgwick, Geological Transactions, Second Series, vol. iii. p. 120.

England and Germany, may have arisen in great part from the disintegration of various crystalline or metamorphic schists; and sometimes, as in parts of Saxony and Devonshire, from porphyritic trap rocks containing much oxide of iron. In some districts of the eastern Grampians in Scotland, as in the north of Forfarshire, the sides of mountains composed of gneiss, mica-schist, and clay-slate, are covered with alluvium, derived from the disintegration of those rocks; and the mass of detritus is stained by oxide of iron, of precisely the same colour as the Old Red Sandstone of the adjoining Lowlands. Now this alluvium merely requires to be swept down to the sea, or into a lake, to form strata of red sandstone and red marl, similar to those of the "Old Red" or New Red system, or those of the Cretaceous era in Spain (see Vol. I. p. 413.), or those of tertiary origin, as at Coudes and Champheix, in Auvergne (see Vol. I. p. 367.), all of which are in lithological characters quite undistinguishable from one another. The pebbles of gneiss in the tertiary red sandstone of Auvergne point clearly to the rocks from which it has been derived. The red colouring matter may have been furnished by the decomposition of hornblende, or mica, which contain oxide of iron in large quantity (see Table at end of Chap. XXVII.).

It is a general fact, and one not yet accounted

for, that scarcely any fossil remains are preserved in stratified rocks in which this oxide of iron abounds; and when we find fossils in the New or Old Red Sandstone in England, it is in the grey, and usually calcareous beds, that they occur.

CHAPTER XXIII.

THE COAL, OR CARBONIFEROUS GROUP.

Carboniferous strata in the south-west of England — Superposition of Coal-measures to Mountain limestone — Departure from this type in north of England and Scotland — Freshwater strata — Intermixture of freshwater and marine beds — Sauroidal fish — Fossil plants — Ferns and Sigillariæ — Lepidodendra and Lepidostrobus — Calamites — Coniferæ — Stigmariæ.

The next group which we meet with in the descending order is the Carboniferous, commonly called "The Coal;" because many beds of that mineral, in a more or less pure state, are interstratified with sandstone, shale, and limestone, of which the bulk of the formation is made up. The combustible coal itself, even in Great Britain and Belgium, where it is most abundant, constitutes but a small proportion of the whole mass. In the north of England, for example, the thickness of the coal-bearing strata has been estimated at 3000 feet, while the various coal-seams, 20 or 30 in number, do not exceed 60 feet.*

* Phillips; art. "Geology," Encyc. Britan.

In the south-west of England, in Somersetshire, and in South Wales, the Carboniferous series consists of,

1st, Coal measures.	Strata of shale, sandstone, and grit, with occasional seams of coal, sometimes exceeding 600 feet in thickness.
2d, Millstone grit.	A coarse quartzose sandstone passing into a conglomerate, sometimes used for millstones; usually devoid of coal; occasionally above 600 feet thick.
3d, Mountain or Carboniferous limestone.	A calcareous rock containing marine shells and corals; devoid of coal; thickness variable, sometimes 900 feet.

Beneath all these is the Old Red Sandstone, which was formerly considered as part of the Carboniferous series; but which, now that its organic remains are better known, appears entitled to rank as a distinct formation.

As we proceed northwards from South Wales and Somersetshire to Yorkshire and the more northern counties, we find the Carboniferous group beginning gradually to assume a new character, there being first a slight intermixture of the Coal-measures and Mountain limestone at their contact, and these alternations taking place afterwards on a still greater scale. The Coal, in Yorkshire, does not cease when we reach the Millstone-grit, although it is there in diminished quantity; and beneath that grit is a complex deposit, 1000 feet thick, of limestones, alternating with coal-bearing

sandstones and shale, below which comes the great mass of Mountain limestone.* In Scotland we observe a still wider departure from the type of the south of England, the mixture of marine limestone with sandstone and shale containing coal being more complete.

The importance of the coal in England, considered economically, is greatly enhanced by the rich beds of iron-ore which occur in the associated shales, and the contiguity of the mountain limestone, which is required as a flux to reduce the iron-ore to a metallic state.†

It is now generally admitted that all coal is of vegetable origin, the vegetable structure being still recognizable in many kinds of coal, when slices thin enough to transmit light are obtained and examined by the microscope. Impressions also of plants, together with entire trunks of trees, are frequently met with in the accompanying shale and sandstone; leaves also, and small branches, and fruits, occur in nodules of clay-ironstone, the inclosed vegetable having served as a nucleus round which the ferruginous matter, usually carbonate of iron, has concreted. Some of the coal-measures are of freshwater origin, and may have been formed in lakes; others seem to have been

* Sedgwick, Geol. Trans., Second Series, vol. iv.; and Phillips, Geol. of Yorksh. part 2.

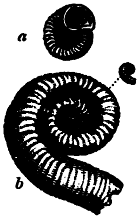
† Conybeare, Outlines, &c., p. 333.

deposited in estuaries, or at the mouths of rivers, in spaces alternately occupied by fresh and salt water.

Thus a freshwater deposit, near Shrewsbury, has been ascertained by Mr. Murchison to be the youngest member of the carboniferous series of that district, at the point where the Coal-measures pass into the lower New Red formation. It consists of shales and sandstones about 150 feet thick, with coal, and traces of plants; including a bed of limestone, varying from two to nine feet in thickness, which is cellular, and resembles the lacustrine limestone of France and Germany. It has been traced for 30 miles in a straight line, and recognized at more distant points. The characteristic fossils are a small bivalve, having the

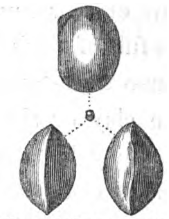
Fresh-water fossils. — Coal.

Fig. 298.



a. Microconchus carbonarius.
b. var. of same; nat. size, and magnified.

Fig. 299.



Cypris inflata, natural size, and magnified. Murchison.*

form of a *Cyclas*, a small *Cypris* (Fig. 299.), and a microscopic shell (*Microconchus*) of an extinct genus.

* Silurian System, p. 84.

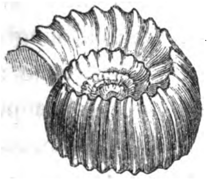
But in the lower coal-measures of Coalbrook Dale, the strata, according to Mr. Prestwich, often change completely within very short distances, beds of sandstone passing horizontally into clay, and clay into sandstone. The coal-seams often wedge out or disappear; and sections, at places nearly contiguous, present marked lithological distinctions. In this single field, in which the strata are from 700 to 800 feet thick, between 40 and 50 species of terrestrial plants have been discovered, besides several fishes and trilobites; the latter distinct in form from those occurring in the Silurian strata. Also upwards of 40 species of mollusca, among which are two or three of the fresh-water genus *Unio*, and others of marine forms, such as *Nautilus*, *Orthoceras*, *Spirifer*, and *Productus*. Mr. Prestwich suggests that the intermixture of beds containing fresh-water shells with others full of marine remains, and the alternation of coarse sandstone and conglomerate with beds of fine clay or shale containing the remains of plants, may be explained by supposing that the deposit of Coalbrook Dale originated in a bay of the sea or estuary into which flowed a considerable river subject to occasional freshes.*

In the Edinburgh coal-field, at Burdiehouse,

* Prestwich, Geol. Trans., 2d Series, vol. v. p. 440. Murchison, Silurian System, p. 105.

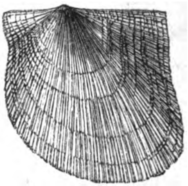
fossil fishes, mollusca and cypris, very similar to those in Shropshire and Staffordshire, have been found by Dr. Hibbert.* In the coal-field also of Yorkshire there are freshwater strata, some of which contain shells referred to the genus *Unio;* but in the midst of the series there is one thin but very widely spread stratum, abounding in fishes and marine shells, such as *Ammonites Listeri* (Fig. 300.), *Orthoceras*, and *Avicula papyracea*, Goldf. (Fig. 301.†)

Fig. 300.



Ammonites Listeri, Sow.

Fig. 301.



Avicula papyracea, Goldf.
(*Pecten papyraceus*, Sow.)

No similarly intercalated layer of marine shells has been noticed in the neighbouring coal-field of Newcastle, where, as in South Wales and Somersetshire, the marine deposits are entirely below those containing terrestrial and fresh-water remains.‡

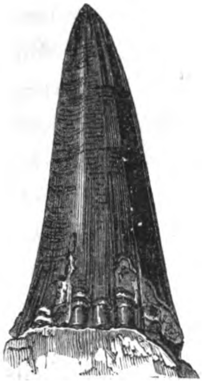
* Trans. Roy. Soc. Edin. vol. xiii. Horner, Edin. New Phil. Journ., April, 1836.

† Phillips; art. "Geology," Encyc. Metrop., p. 590.

‡ Ibid., p. 592.

No bones of mammalia or reptiles have as yet been discovered in strata of the carboniferous group. The fish are numerous, and for the most part very remote in their organization from those now living, as they belong chiefly to the Sauroid family of Agassiz; as *Megalichthys*, *Holoptychus*, and others, which are often of great size, and all predaceous. Their osteology, says M. Agassiz, reminds us in many respects of the skeletons of saurian reptiles, both by the close sutures of the bones of the skull, their large conical teeth striated longitudinally (see Fig. 302.), the articulations of the spinous processes with the vertebræ, and other characters. Yet they do not form a family intermediate between fish and reptiles, but are true *fish*.*

Fig. 302.



Megalichthys Hibberti, Ag. Edinburgh coal-field; natural size.

The annexed figure represents a large tooth of the *Megalichthys*, found by Mr. Horner in the Cannel coal of Fifeshire. It probably inhabited an estuary, frequenting both the mouths of rivers and the sea.

Fossil Plants of the Coal. — But the flora of the coal forms the most interesting feature in its pa-

* Agassiz, Poiss. Foss., livr. 4. p. 62. and livr. 5. p. 88.

læontology, and is far better known to us than any other flora antecedent to the tertiary era. About 300 species of terrestrial plants are enumerated by M. Adolphe Brongniart as proper to the Coal; but botanists have encountered the greatest difficulty in determining the natural affinities of these fossils, it being rare to find in them any vestige of flower, seed, or fruit, those organs which afford the most convenient characters for classifying living plants. They have been obliged, therefore, first to study more minutely the different forms of bark in existing trees, their various modes of branching, the tissue of their wood, nervures of the leaves, and other peculiarities of vegetable structure which might enable them to institute a direct comparison between the analogous parts of recent and fossil plants.*

The most common of these vegetable remains may be provisionally classed under the following heads: — First, Ferns and Sigillariæ; secondly, Lepidodendra, allied to *Lycopodiaceæ?* thirdly, Calamites, allied to *Equisetaceæ?* fourthly, Coniferous plants; fifthly, Stigmariæ, apparently an extinct family of plants.

Ferns and Sigillariæ. — The leaves, or more properly speaking the fronds of ferns (see Figs. 303,

* See the works of MM. Ad. Brongniart, Sternberg, and others, and the Fossil Flora of Lindley and Hutton.

304.), for the most part destitute of fructification, exceed in number all other plants in the shale of the coal. They have been divided by M. Ad. Brongniart into genera, characterized chiefly by the branching of the fronds, and the way in which the veins of the leaves are disposed. These fronds are often accompanied by large fluted stems or

Fig. 303.

Pecopteris lonchitica.
(Foss. Flo. 153.)

Fig. 304.

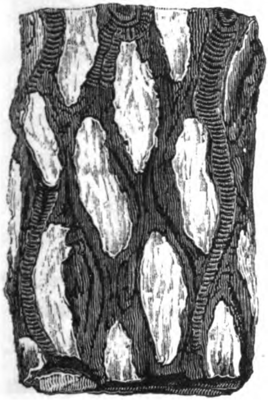
a. *Sphenopteris crenata.*
b. The same, magnified.
(Foss. Flo. 101.)

trunks of trees which have been squeezed down and flattened as they lay prostrate in the shale, so that the opposite sides meet, but which when they occur in the accompanying grit or sandstone,

and are placed obliquely or vertically to the planes of stratification, are round and uncompressed. Their bark has been converted into coal; and they must have been hollow when first deposited, for the interior became filled, not only with sand, but with leaves and branches of ferns, introduced from above. Impressions of these fronds are now frequent in the pillars of sandstone, which may be regarded as casts of the interior of those ancient trees. Most of the trunks or stems now alluded to have been called *Sigillariæ*. They vary from half a foot to five feet in diameter, and must have been sometimes forty or fifty feet high.

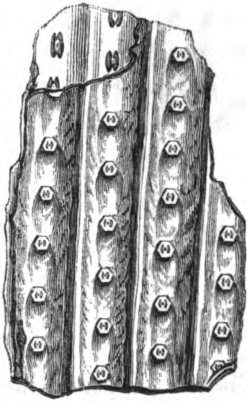
It is admitted by all botanists that some of these gigantic stems, all of which are comprehended by Brongniart in his genus *Sigillaria*, were true

Fig. 305.



***Sigillaria Lindleyi*, Brong.**
(*Caulopteris primæva*, Lindley.)

Fig. 306.



Sigillaria lævigata, Brong.

arborescent ferns; as, for example, that section which has been named *Caulopteris* by Lindley and Hutton. (See Fig. 305.) But these are comparatively rare, whereas of the other section (Fig. 306.) more than forty species have been described. In these the scars on the stem are smaller and more regularly arranged in parallel series on the fluted bark (Fig. 306.).

The recent tree-ferns belong to one tribe (*Polypodiaceæ*), and to a small number only of genera in that tribe, in all of which the surface of the trunk is marked with scars, or cicatrices, left after

Fig. 307. Fig. 308. Fig. 309.

Living Tree Ferns of different Genera. (Ad. Brong.)

Fig. 307. Tree-fern from Isle of Bourbon.
Fig. 308. *Cyathea glauca*, Mauritius.
Fig. 309. Tree-fern from Brazil.

the fall of the fronds. These scars are precisely similar to those of *Caulopteris* (Fig. 305.); but Mr. Lindley objects to the opinion that the remaining *Sigillariæ* of Brongniart were Tree-ferns, because the scars in these are smaller, dissimilar in form, and more regularly arranged in parallel lines; also, because the stems are fluted (see Fig. 306.), and sometimes bifurcating. M. Brongniart has replied, that the forking of the stems of some of the fossil trees is no more than might have been expected from their large size; and as to the forms of the discs or scars from which the fronds have fallen, their individual variations are not greater than those which we find in the fronds of different genera of living ferns, which do not in the present state of the globe attain the size of trees.

Lepidodendra. — Another class of fossils, very common in the coal-shales, have been named *Lepidodendra*. Some of these are of small size, and approach very near in form to the modern *Lycopodiums*, or club-mosses, while others of much larger dimensions are supposed to have been intermediate between these and coniferous plants. The annexed figures represent a large fossil *Lepidodendron*, forty-nine feet long, lately found in Jarrow Colliery, near Newcastle, lying in shale parallel to the planes of stratification. Fragments of others, found in the same shale, indicate by the

size of the rhomboidal scars which cover them a still greater magnitude. The living club-mosses,

Fig. 310.

Fig. 311.

Fig. 312.

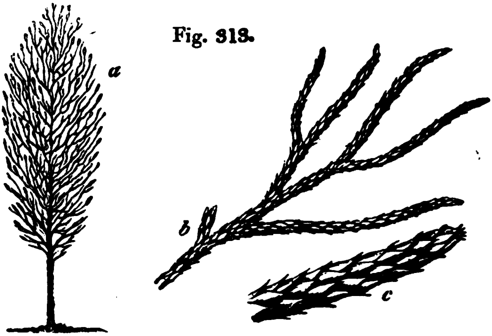
Lepidodendron Sternbergii. Coal-measures, near Newcastle.

Fig. 310. Branching trunk, 49 feet long, supposed to have belonged to *L. Sternbergii.* (Foss. Flo. 203.)

Fig. 311. Branching stem with bark and leaves of *L. Sternbergii.* (Foss. Flo. 4.)

Fig. 312. Portion of same nearer the root; natural size. (Ibid.)

Fig. 313.

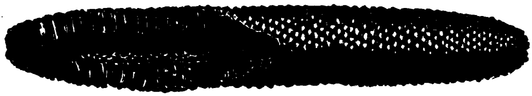


a. Lycopodium densum; banks of R. Thames, New Zealand.
b. branch, natural size. *c.* part of same, magnified.

of which there are about 200 species, are abundant in tropical climates, where one species is sometimes met with attaining a height of three feet. They usually creep on the ground, but some stand erect, as the *L. densum*, from New Zealand (Fig. 313.).

In the carboniferous strata of Coalbrook Dale, and in many other coal-fields, elongated cylindrical bodies, called fossil cones, named by M. Adolphe Brongniart *Lepidostrobus*, are met with. (See

Fig. 314.



Lepidostrobus ornatus, Brong.; half nat. size. Shropshire.

Fig. 314.) They often form the nucleus of concretionary balls of clay-ironstone, and are well preserved, exhibiting a conical axis, around which a great quantity of scales were compactly imbricated. The opinion of M. Brongniart is generally adopted, that the *Lepidostrobus* is the fruit of *Lepidodendron*.

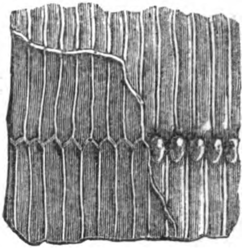
Calamites. — These fossils have a jointed stem longitudinally striated, and are supposed by M. Brongniart to have been allied to the *Equisetaceæ*, or horse-tail tribe; aquatic plants which, in a living state, are only two or three feet high in our climates, and even in tropical countries only attain, as in the case of *Equisetum giganteum*, discovered

by Humboldt and Bonpland, in South America, a height of about five feet, the stem being an inch in diameter. The *Calamites*, however, of the Coal differed from these principally in being furnished with a thin bark, which is represented in the stem of *C. Suckowii* (Fig. 316.), in which it will be seen

Fig. 315.

Calamites cannæformis, Schlot. (Foss. Flo. 79.) Common in English coal.

Fig. 316.



Calamites Suckowii, Brong.; natural size. Common in coal throughout Europe.

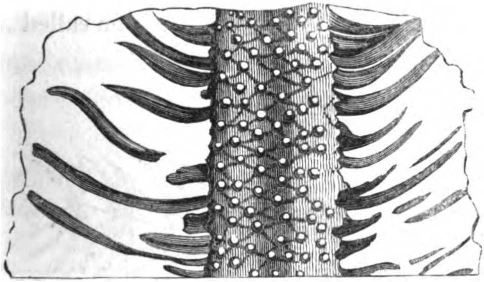
that the striped external pattern does not agree with that left on the stone where the bark is stripped off; so that if the two impressions were seen separately, they might be mistaken for two distinct species.

Coniferæ.—The structure of the wood of certain coal plants displays so great an analogy to that of certain pines of the genus *Araucaria*, as to lead to the opinion that some species of firs existed at this period. (See above, p. 85.)

Stigmariæ. — Fragments of a plant which has been called *Stigmaria ficoides* occur in great num-

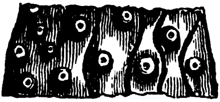
bers in almost every coal-pit. It is supposed to have been a huge succulent water-plant of an extinct family; thin transparent sections of the stem exhibiting an anatomical structure quite different from the wood of any living tree.* According to

Fig. 317.



Stigmaria ficoides, Brong. One fourth of nat. size. (Foss. Flo. 32.)

Fig. 318.



Surface of another individual of same species, showing form of tubercles. (Foss. Flo. 34.)

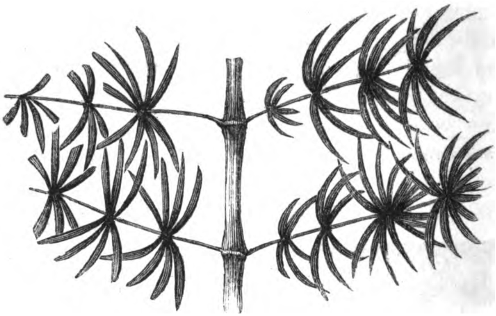
the conjectures of some botanists, it approached most nearly to the family *Lycopodiaceæ*; according to others, to *Euphorbiaceæ*. Mr. Hutton discovered one of these *Stigmariæ* forming a huge dome-shaped body, from which twelve branches spread horizontally in all directions, each, usually dividing into two arms, from twenty to thirty feet long, to which leaves of great length were attached. Dr. Buckland imagines these

* Lindley, Foss. Flora, p. 166.

plants to have grown in swamps, or to have floated in lakes like the modern *Stratiotes.**

Besides the five classes which have been enumerated, there are other fossil plants, of which the nature is more obscure, and of which no traces have been found among existing vegetables, nor in any strata more recent than the coal. Some of the most abundant of these have been called *Asterophyllites.*

Fig. 319.



Asterophyllites foliosa. (Foss. Flo. 25.) Coal-measures, Newcastle.

I shall postpone some general remarks on the climate of the Carboniferous period, arising out of the contemplation of its flora, until something has been said of the contemporaneous Mountain limestone and its marine fossils.

* Bridgew. Treat., p. 478.

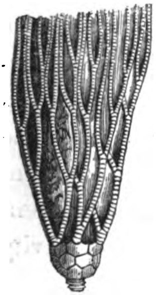
CHAPTER XXIV.

CARBONIFEROUS GROUP *continued.*

Corals and shells of the Mountain limestone — Hot climate of the Carboniferous period inferred from the marine fossils of the Mountain limestone and the plants of the Coal — Origin of the Coal-strata — Contemporaneous freshwater and marine deposits — Modern analogy of strata now in progress in and around New Zealand — Vertical and oblique position of fossil trees in the Coal — How enveloped — How far they prove a rapid rate of deposition.

Carboniferous or Mountain Limestone. — We have already seen that this rock lies sometimes entirely beneath the Coal-measures, while, in other districts, it alternates with the shales and sandstone of the Coal. In both cases it is destitute of land plants, and usually charged with corals, which are often of large size; and several species belong to the lamelliferous class of Lamarck, which enter largely into the structure of coral reefs now growing. There are

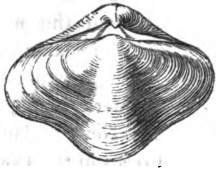
Fig. 320.



Cyathocrinites planus, Miller. Mountain Limestone.

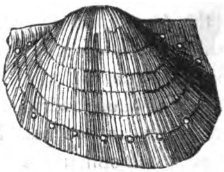
also a great number of *Crinoidea* (see Fig. 320.), and a few *Echinida*, associated with the zoophytes above mentioned. The *Brachiopoda* constitute a large proportion of the Mollusca, many species being referable to two extinct genera, *Spirifer* (or *Spirifera*, Fig. 321.), and *Producta* (*Leptæna*), Fig. 322.

Fig. 321.



Spirifera glabra, Sow.* Mountain limestone.

Fig. 322.



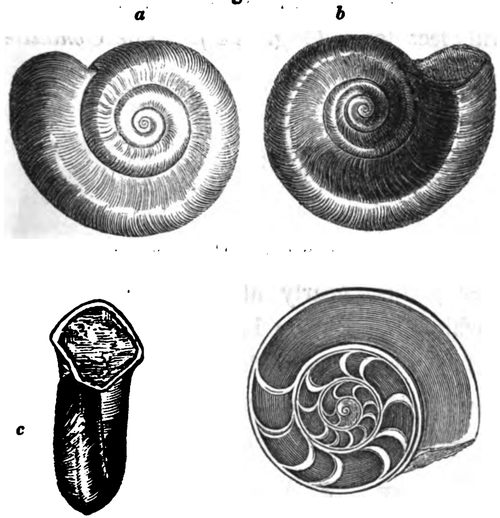
Producta Martini, Sow.† Mountain limestone.

Among the spiral univalve shells the extinct genus *Euomphalus* (see Fig. 323.) is plentifully represented in the fossils of the Mountain limestone. In the interior it is often divided into chambers (see Fig. 323. *d*); the septa or partitions not being perforated, as in foraminiferous shells, or in those having siphuncles, like the Nautilus. The animal appears, like the recent *Bulimus decollatus*, to have retreated, at different periods of its growth, from the internal cavity

* Phillips, Geol. of Yorksh. pl. 10. fig. 11.
† Ibid., pl. 8. fig. 19.

previously formed, and to have closed all communication with it by a septum. The number of chambers is irregular, and they are generally wanting in the innermost whorl.

Fig. 323.



Euomphalus pentagulatus, Min. Con. Mountain limestone.

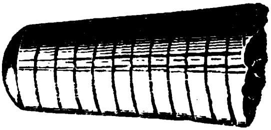
a. upper side; *b.* lower, or umbilical side; *c.* view showing mouth which is less pentagonal in older individuals; *d.* view of polished section, showing internal chambers.

There are also many univalve and bivalve shells of existing genera in the Mountain limestone, such as *Turritella*, *Buccinum*, *Patella*, *Isocardia*, *Nucula*, and *Pecten.** But the Cephalopoda

* Ibid., vol. ii. p. 208.

depart, in general, more widely from living forms, some being generically distinct from all those found in strata newer than the Coal. In this number may be mentioned *Orthoceras*, a siphuncled and chambered shell, like a *Nautilus* uncoiled and straigthened. Some species of this genus are several feet long (Fig. 324.). The *Goniatite* is

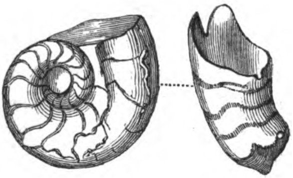
Fig. 324.



Portion of Orthoceras laterale, Phillips. Mountain limestone.

another genus, nearly allied to the *Ammonite*, from which it differs in having the lobes of the septa free from lateral denticulations, or crenatures; so that the outline of these is continuous

Fig. 325. *a*



Goniatites evolutus, Phillips.*
Mountain limestone.

Fig. 326.

Bellorophon costatus, Sow.†
Mountain limestone.

and uninterrupted (see *a*, Fig. 325.). Their siphon is small, and in the form of the striæ of

* Phillips, Geol. of Yorksh., pl. 20. fig. 65.
† Ibid., pl. 17. fig. 15.

growth they resemble *Nautili.* Another extinct generic form of Cephalopod, abounding in the Mountain limestone, and not found in strata of later date, is the *Bellerophon* (Fig. 326.), of which the shell, like the living Argonaut, was without chambers.

Climate of the Carboniferous period.—The abundance of lamelliferous and other corals, of large chambered Cephalopods and Crinoidea, naturally leads us to infer that the waters of the sea, at this period, were of a far warmer and more equable temperature than is now experienced in those latitudes where the coal strata abound, in Europe. M. Adolphe Brongniart has been led to a similar conclusion in regard to the temperature of the air, from considering the Carboniferous flora. The unquestioned existence of large tree-ferns, such as *Caulopteris* (Fig. 305.), now exclusively the inhabitants of hot and humid climates, and the great variety of fossil fronds of ferns in the Coal confirm this idea, even if we refuse to accede to the arguments adduced to prove that *Sigillariæ* were tree-ferns of extinct genera. The same views receive farther countenance, if the *Lepidodendra* and *Calamites* are rightly conjectured to have been gigantic plants of the orders *Lycopodiaceæ* and *Equisetaceæ*, which, although most largely developed at present in the tropical zone, are even there of pigmy stature, in comparison with

the fossil tribes just alluded to. The *Araucaria*, also, is a family of pines now met with in temperate and warm latitudes; and the fir trees proper to the forests of arctic regions do not appear to have any fossil representatives in the Coal. M. Ad. Brongniart, when endeavouring to establish the great heat and moisture of the climate of the era under consideration, may perhaps have relied too much on the numerical preponderance of ferns over other orders of coal-plants. We may easily be deceived by such reasoning, because it is founded on negative facts, or the absence of plants of certain orders, families, and genera. On this subject Professor Lindley has observed, that the small variety in the forms of each fossil flora must, in a great degree, depend on the relative destructibility of plants when suspended in water before they are imbedded in strata. In illustration of this point, he threw into a vessel containing fresh water 177 plants, among which were species of all the orders found in the Carboniferous flora, with others representing the remaining families and natural orders in the living creation, and found that, at the end of two years, all had decayed and disappeared except the ferns, palms, *Lycopodiaceæ*, and *Coniferæ*. The fructification of the ferns had also vanished, but the form and nervures of the leaves remained.*

* Lindley, Foss. Flora, part 17.

No inference, however, drawn from this experiment, can entirely explain away the fact of the vast preponderance in the coal-shales of fern-leaves over those of Dicotyledonous plants. Impressions of these last, together with their wood, are plentifully preserved in tertiary rocks in which fossil ferns are rare; and had they been drifted down in as large numbers as ferns into the estuaries of the Carboniferous period, they would have left impressions of their shape in shale and sandstone, as they have done in more recent formations.

It would, moreover, be rash to assume that the coal-plants in general floated about in water for a year or two before they were enveloped in sediment. It is more probable that a large part of them were deposited immediately with the mud and sand swept down with them by rivers into lakes or the sea. This must have happened in those rare cases where the ferns still retain their fructification. Where this has disappeared, its decomposition may often have been subsequent to the inclosure of the frond in mud or sand.

Origin of the Coal Strata. — It has been already shown (pp. 107, 108.) that, in some parts of England, as in Shropshire, certain Coal-measures consist of freshwater strata, and may have originated in a lake; while others, not far distant, were deposited in estuaries to which the sea obtained

access occasionally; while a third class were formed at the bottom of an open sea, or in bays of salt water, into which land plants were drifted.

The minor repetitions of alternate fresh and saltwater strata in the Coal, have been ascribed to such changes as may annually occur near the mouths of rivers; but when shale and grit, containing coal and freshwater shells, are covered by large masses of coralline rock, such as the Mountain limestone, and this again by other Coal-measures, we must suppose great movements of elevation and subsidence, like those by which I endeavoured to explain, in Chapters XVIII. and XX., the superposition of the Cretaceous group to the Wealden, or the alternations of argillaceous and calcareous rocks in the Oolite.

If the superposition, on a great scale, of purely marine strata to others containing Coal and freshwater shells leads us to infer that large areas, once constituting estuaries, deltas, and marshes, sank down and became sea during the carboniferous period, so are there reasons for concluding that in many cases the depression of the ground took place gradually, and that, in consequence of the deposition of sediment, the same space was again and again converted into land, and laid under water. And here I may observe, that two opposite theories have been advanced respecting the probable manner in which beds of coal were formed;

according to one, the vegetables grew upon the strata now lying immediately beneath them; according to the other, they were drifted by rivers and marine currents to the situations where we now find them. It can no longer be doubted that both these opinions are true, if we confine our attention to particular places. "Some of the plants of our coal," says Dr. Buckland, "grew on the identical banks of sand, silt, and mud, which, being now indurated to stone and shale, form the strata that accompany the coal; whilst other portions of these plants have been drifted to various distances from the swamps, savannahs and forests that gave them birth, particularly those that are dispersed through the sandstones, or mixed with fishes in the shale beds." "At Balgray, three miles north of Glasgow," says the same author, "I saw, in the year 1824, as there still may be seen, an unequivocal example of the stumps of several stems of large trees standing close together in their native place, in a quarry of sandstone of the coal formation." *

Between the years 1837 and 1840, six fossil trees were discovered in the coal-field of Lancashire, where it is intersected by the Bolton railway. They are all in a vertical position, with respect to

* Anniv. Address to Geol. Soc., 1840.

the plane of the bed, which dips about 15° to the south. The distance between the first and the last is more than 100 feet, and the roots of all are imbedded in a soft argillaceous shale. In the same plane with the roots is a bed of coal, eight or ten inches thick, which has been ascertained to extend across the railway, or to the distance of at least ten yards. Just above the covering of the roots, yet beneath the coal seam, so large a quantity of the *Lepidostrobus variabilis* was discovered inclosed in nodules of hard clay, that more than a bushel was collected from the small openings around the base of the trees (see figure of this genus, p. 117.). The exterior trunk of each was marked by a coating of friable coal, varying from one quarter to three quarters of an inch in thickness; but it crumbled away on removing the matrix. The dimensions of one of the trees is 15½ feet in circumference at the base, 7½ feet at the top, its height being 11 feet. All the trees have large spreading roots, solid and strong, sometimes branching, and traced to a distance of several feet, and presumed to extend much farther. Mr. Hawkshaw, who has described these fossils, thinks that, although they were hollow when submerged, they may have consisted originally of hard wood throughout; for solid dicotyledonous trees, when prostrated in tropical forests, as in Venezuela, on the shore of the Caribbean Sea, were observed by

him to be destroyed in the interior, so that little more is left than an outer shell, consisting chiefly of the bark. This decay, he says, goes on most rapidly in low and flat tracts, in which there is a deep rich soil and excessive moisture, supporting tall forest-trees and large palms, below which bamboos, canes, and minor palms flourish luxuriantly. Such tracts, from their lowness, would be most easily submerged, and their dense vegetation might then give rise to a seam of coal.*

If from the upright position of the trees before mentioned, in Lancashire, the spreading of their roots into the shale below, and the layer of coal extending from their base, we infer that they flourished on the spots where they afterwards became fossil, we are also led by other facts lately brought to light in the South Wales coal-field, to believe that the same area was repeatedly submerged, and then again converted, first into marshy, and then dry land. Thus, for example, Mr. Logan has ascertained, that immediately below every regular seam of coal, of which nearly 100 are known in South Wales, lies a bed of clay, varying in thickness from 6 inches to more than 10 feet, called "the under-clay." It is so constant, that the collier regards it as an essential accompaniment of the coal: although always argillaceous,

* Hawkshaw, Geol. Soc. Proceedings, Nos. 64. and 69.

it is never without a considerable admixture of sand, and is occasionally quite black, in consequence of the presence of carbonaceous matter. These strata of clay are most strongly marked by containing *Stigmaria ficoides* (Fig. 317. p. 119.) in great numbers; the stems of which are usually of considerable length, lying parallel to the plane of the bed, and nearer to the top than the bottom. In diameter they vary from two to six inches, and they are occasionally compressed. Their long slender processes, covered with a pellicle of carbonaceous matter, form an entangled mass, and traverse the beds in every direction, vertically, horizontally, and obliquely; but Mr. Logan has never been able to trace them to their termination, though he has followed single processes for considerable distances. Portions of the stem of the *Stigmaria* are found in other parts of the coal-measures, but it is only in the under-clay that the fibrous processes are attached to the stem or associated with it.*

When it is considered, that over so large an area as the coal-field of South Wales not a seam has been discovered without an underclay abound-in *Stigmaria*, it is reasonable to conclude that this plant has contributed largely to the formation of coal. It is supposed that it grew in lakes and

* Logan, Proceedings Geol. Soc., No. 67.

marshes, with its roots in the argillaceous mud, until by the accumulation of sediment and vegetable matter the space was turned into land fit for trees and shrubs of other species. By this process, the lowest part of each coal-seam may have been derived from *Stigmaria*, and the higher portions composed of the remains of other vegetables.

In a deep valley near Capel-Coelbren, branching from the higher part of the Swansea valley, four stems of upright *Sigillariæ* were seen, in 1838, piercing through the coal-measures of S. Wales; one of them was 2 feet in diameter, and one 13 feet and a half high, and they were all found to terminate downwards in a bed of coal. "They seem," says Mr. De la Beche, "to have constituted a portion of a subterranean forest at the epoch when the lower carboniferous strata were formed." *

In a colliery near Newcastle, say the authors of the Fossil Flora, a great number of *Sigillarias* were placed in the rock as if they had retained the position in which they grew. Not less than 30, some of them 4 or 5 feet in diameter, were visible, within an area of 50 yards square, the interior being sandstone, and the bark having been converted into coal. The roots of one indi-

* Geol. Report on Cornwall, &c. p. 143.

vidual were found imbedded in shale; and the trunk, after maintaining a perpendicular course and circular form, for the height of about 10 feet, was then bent over so as to become horizontal. Here it was distended laterally, and flattened so as to be only one inch thick, the flutings being comparatively distinct.* Such vertical stems are familiar to our miners, under the name of coal-pipes. One of them, 72 feet in length, was discovered, in 1829, near Gosforth, about five miles from Newcastle, in coal-grit, the strata of which it penetrated. The exterior of the trunk was marked at intervals with knots, indicating the points at which branches had shot off. The wood of the interior had been converted into carbonate of lime; and its structure was beautifully shown by cutting transverse slices, so thin as to be transparent. (See p. 85.)

If we appreciate the full strength of the evidence in favour of continued subsidence in the coal-field of South Wales, we shall be the less surprised to learn that the vertical depth of the superimposed strata is enormous, amounting in some places to no less than 12,000 feet. Nor are other signs wanting of great geological and geographical changes having been brought about during the deposition of this enormous mass of sediment. Thus, for ex-

* Lindley and Hutton, Foss. Flo., part 6. p. 150.

ample, boulders of the more ancient rocks of the Carboniferous series have been found in some of the upper and newer members of the same formation. Rounded masses of cannel coal six inches long, pebbles of ironstone, and bituminous coal, containing *Sigillariæ*, mingled with boulders of granite and mica-slate, are met with in the Pennant grit, a mass of sandstone, 3000 feet thick, which overlies the lower coal measures.* Some portions of these last had therefore been denuded, and probably upraised above the level of the sea before the deposition of the higher members of the series was concluded.

M. Ad. Brongniart, after comparing the phenomena of the ancient Coal and its fossil plants with the great peat-mosses of the present day, states, in a memoir published in 1838, that he continues to adhere to the opinions originally advanced by Werner and De Luc, that the vegetation entombed in the Carboniferous strata chiefly grew in the localities where the coal is now found. Certainly we are not entitled to cherish any disinclination to this hypothesis, on the ground of the reiterated depressions of land, which must be assumed, unless we wholly reject the evidence in favour of Mr. Darwin's theory, that all circular coral reefs owe their shape to the gradual subsidence of the ocean's bed, continued

* Logan, Geol. Soc. Proceedings, No. 69.

for ages, and now in progress.* Within the lagoons encircled by these reefs, groves of the cocoa-nut and other trees have been found submerged after earthquakes in modern times. In like manner, in the year 1819, extensive flats bordering the Indus sank down, and, for many years after, vessels were forced through the boughs of the tamarisk trees, still standing erect, and with their roots still fixed in the muddy sediment below.†

But there are many cases where the fossil trees of the coal are in a position either perpendicular or oblique to the planes of stratification, and where, nevertheless, we cannot reconcile the phenomena with the idea of their having grown on the places where they are now buried.

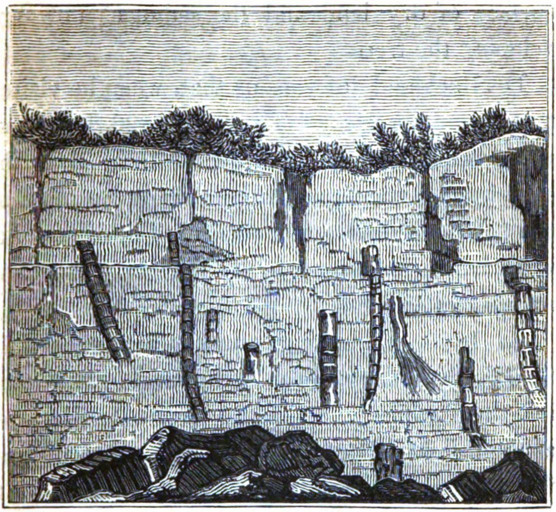
In the account given, in 1821, by M. Alex. Brongniart of the coal-mine of Treuil, at St. Etienne, near Lyons, he states, that distinct horizontal strata of micaceous sandstone are traversed by vertical trunks of Monocotyledonous vegetables, resembling bamboos or large *Equiseta*.‡ Since the consolidation of the stone, there has been here and there a sliding movement, which has broken the continuity of the stems, throwing the upper parts of them on one side, so that they are often not continuous with the lower.

* Principles of Geol. ,vol. iii. 6th ed. "Coral reefs."

† Ibid., 'Cutch."

‡ Annales des Mines, 1821.

Fig. 327.



Section showing the erect position of fossil trees in coal sand-stone at St. Etienne. (Alex. Brongniart.)

Although these appearances have been thought to favour the hypothesis of a submerged forest, yet an obvious objection presents itself, that in that case all the roots would have been in the same stratum, or would have been confined to certain levels, and not scattered irregularly through the mass. Besides, when the stems have any roots attached to them, which happens but rarely, they are imbedded in sandstone, precisely similar to that in which the trunks are inclosed; there being no soil of different composition, like the Portland dirt-bed, — no line of demarcation,

however slight, between the supposed ancient surface of dry land and the sediment now enveloping the trees.

Dr. Buckland informs us that, when he visited these same quarries of Treuil, in 1826, he saw so many trunks in an inclined posture, that the occasional verticality of others might be accidental. * Nevertheless, the possibility of so many of them having remained in an upright posture demands explanation.

In 1830, a slanting trunk was exposed in Craigleith quarry, near Edinburgh, the total length of which exceeded 60 feet. Its diameter at the top was about 7 inches, and near the base it measured 5 feet in its greater, and 2 feet in its lesser width. The bark was converted into a thin coating of the purest and finest coal, forming a striking contrast in colour with the white quartzose sandstone in which it lay. The annexed

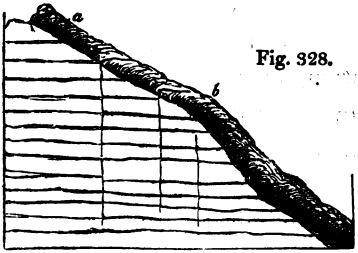


Fig. 328.

Inclined position of a fossil tree, cutting through horizontal beds of sandstone, Craigleith quarry, Edinburgh. Angle of inclination from *a* to *b* 27°.

* Bridgew. Treat., p. 471.

figure represents a portion of this tree, about 15 feet long, which I saw exposed in 1830, when all the strata had been removed from one side. The beds which remained were so unaltered and undisturbed at the point of junction, as clearly to show that they had been tranquilly deposited round the tree, and that the tree had not subsequently pierced through them, while they were yet in a soft state. They were composed chiefly of siliceous sandstone, for the most part white; and divided into laminæ so thin, that from six to fourteen of them might be reckoned in the thickness of an inch. Some of these thin layers were dark, and contained coaly matter; but the lowest of the intersected beds were calcareous. The tree could not have been hollow when imbedded, for the interior still preserved the woody texture in a perfect state, the petrifying matter being, for the most part, calcareous.* It is also clear, that the lapidifying matter was not introduced laterally from the strata through which the fossil passes, as most of these were not calcareous. It is well known that, in the Mississippi and other great American rivers, where thousands of trees float annually down the stream, some sink with their roots downwards, and become fixed in the mud. Thus placed, they have been compared to a lance

* See figures of texture, Witham, Foss. Veget., pl. 3.

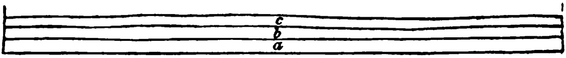
in rest; and so often do they pierce through the bows of vessels which run against them, that they render the navigation extremely dangerous. But the vertical coal-plants did not always retain their roots. Perhaps they sank with their larger end downwards, because the specific gravity of the wood may have been greatest near the lower end. In trees of the Endogenous class, in particular, the wood of the inferior and older part of the trunk is more dense than the upper and younger portions; and if the former should become water-logged while the upper part of the stem still remained nearly as light as water, or even lighter, not only would the whole trunk descend perpendicularly, but when it reached the bottom it might stand upright, provided a very slight support was afforded to its lower extremity by penetrating to the depth of a foot or two into soft mud. How long such trunks, if constantly submerged, might resist decomposition, is a question which cannot, perhaps, be determined; but, judging from the duration of wooden piles constantly covered by water, and trees naturally submerged, like those in Louisiana*, we may conclude that they might endure for many years, so that their envelopment in strata, like those of the Coal, may have been effected without a very rapid rate of deposition.

* See Principles, *Index*, "Bistineau."

If, however, we assume that strata 30 or 40 feet thick were often thrown down in a few years, months, or even days, this fact affords no ground for calculating the time required for the formation of a wide coal-field; although it has furnished a popular argument to some writers who desire to prove the earth's crust to be no more than 5000 or 6000 years old. We can by no means presume that all coal-fields were in progress at once, much less that, in the same field, each mass of strata which is parallel, or occupies a corresponding level, was formed simultaneously. It is far more consistent with analogy to suppose that rivers filled up first one part of a fiord, gulf, or bay, nearest the land, and then another; so that the sea was gradually excluded from certain spaces which it previously occupied.

If the structure of a coal-field always resembled that exhibited in the annexed section (Fig. 329.), we might then infer, that if the lowest set of strata, *a*, having a thickness of fifty feet, required half a century for its accumulation, the strata *a*, *b*, *c*, constituting the entire coal-field, and being 150 feet thick, might have been

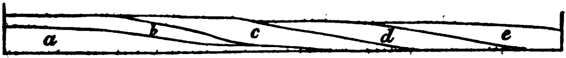
Fig. 329.



completed in a century and a half. But as the beds are wedge-shaped, and often thin out; and

as the successive beds of a single coal-field are usually arranged in the form of *a*, *b*, *c*, *d*, *e* (Fig. 330.), we cannot calculate their number

Fig. 330.



from considering any one section. The deposits, *a*, *b*, *c*, *d*, *e*, traced in a given direction, may have taken each fifty years for their deposition; but they may have been as limited in breadth as in length. They may have constituted originally a narrow strip of land like part of the delta formed by the Mississippi, since New Orleans was built, by the incessant discharge of mud and drift timber into the Gulf of Mexico. Although by this means a narrow tongue of land has been made to protrude for several leagues into the sea, yet thousands of years may elapse before a square area of low land, having a diameter of as many leagues, can be gained from the Gulf of Mexico.

Detached portions of the ancient Carboniferous group extend from Central Europe to Melville Island and the confines of the arctic region, and have been found, with many of the same plants, in Nova Scotia and the United States of North America. Yet they do not appear in the south of Europe; for the lignite and coal found south of the Alps and Pyrenees, in Spain, Italy, Greece, and other countries bordering the Mediterranean,

seem referable to the Cretaceous and other comparatively modern groups.

In many parts of France and Germany there are isolated patches of Coal strata, entirely free from marine fossils, which repose on granite and other hypogene rocks. They are often confined to an extremely small area, as at St. Etienne, in the department of the Loire; at Brassac, in that of Puy de Dome; at Sarrebruck; also in Silesia, and a hundred other places. All these deposits may have been formed in lakes, existing in the islands of that sea in which the Mountain limestone was formed.*

If the climate of New Zealand and the surrounding ocean was warmer, so that tree-ferns could thrive more luxuriantly on the land, and corals build reefs in the sea, we might conceive new strata to accumulate in that part of the globe, analogous to those of the ancient Coal. The two islands of New Zealand are between 800 and 900 miles in length; and through the middle of them runs a lofty chain of mountains, said, in some parts, to be 14,000 feet high, and covered with perpetual snow. Many rivers descend from their sides; and, in the spring, these are copiously charged with sediment, and with abundance of drift wood. Opposite the mouths of these rivers,

* Burat's D'Aubuisson, tom. ii. p. 268.

and near the shores, wherever these may be wasting by the action of the waves, an irregular zone of gravel, sand, and mud must be forming in the surrounding sea — a zone several thousand miles in circumference. No less than 57 species of ferns, some few of them arborescent, have been already discovered in this country; and what is remarkable, one tree-fern ranges in this country as far south as the 46th degree, south latitude. There are no indigenous mammalia, except one rat, and a species of bat; few reptiles, and none of large size; so that we may anticipate a total absence of the bones of land quadrupeds, and a scarcity of those of reptiles, in the modern estuary and lacustrine deposits of this region. That there are lacustrine strata now in progress is certain, since one lake, called Rotorua, in the interior of the northern island, is said to be 40 miles long, and receives the waters of many small rivers and torrents.*

* Account of New Zealand, published for New Zealand Association.

CHAPTER XXV.

OLD RED SANDSTONE, OR DEVONIAN GROUP.

"Old Red" of Scotland, and borders of Wales — Fossils usually rare — Ichthyolites of Caithness — Distinct lithological type of Old Red in Devon and Cornwall — Term "Devonian." — Organic remains of intermediate character between those of Carboniferous and Silurian systems — Corals and shells — Devonian strata of Westphalia, the Eifel, and Russia.

It was stated in the 22nd chapter that the Carboniferous formation is surmounted by one called the "New Red," and underlaid by another called the "Old Red Sandstone." The strata of the last mentioned series have long been recognized in Herefordshire and Scotland as immediately subjacent to the coal, but they are in general so barren of organic remains, that until within the last few years it was difficult to find characters of sufficient importance to distinguish them as an independent group. In Scotland, and on the borders of Wales, the Old Red Sandstone consists chiefly of red arenaceous stone, conglomerate, and shale, with few fossils; but strata of the same age have recently been recognized in Devonshire which wear another lithological aspect, and are peculiarly rich in fossils.

I shall first advert to the more northern type, which is largely developed in Herefordshire, Worcestershire, Shropshire, and South Wales. Its thickness has been estimated by Mr. Murchison at 10,000 feet, and in describing it he adopts the triple subdivision formerly proposed by Messrs. Buckland and Conybeare, namely:—

1st, A quartzose conglomerate passing downwards into chocolate-red and green sandstone and marl.

2d. Cornstone and marl (red and green argillaceous spotted marls, with irregular courses of impure concretionary limestone, provincially called Cornstone, mottled, red, and green; remains of fishes).

3d. Tilestone (finely laminated hard reddish or green micaceous or quartzose sandstones, which split into tiles; remains of mollusca and fishes).

Although here, as usual, fossils are extremely rare in those marls and sandstones in which the red oxide of iron prevails; some remains of fishes of the genera *Cephalaspis* and *Onchus* have been discovered in the Cornstone.* In the grey Tilestones also, *Icthyodorulites*, of the genus *Onchus*, have been obtained, together with a species of *Dipterus*. With these also have been found some shells referred to the genera *Avicula*, *Arca*, *Cucullæa*, *Terebratula*, *Lingula*, *Turbo*, *Trochus*, *Turritella*, *Bellerophon*, *Orthoceras*, and others.†

* Murchison's Silurian System, p. 180. † Ibid. p. 183.

The whole of the northern part of Scotland, from the southern flank of the Grampians to Cape Wrath, has been well described by Mr. Miller as consisting of a nucleus of granite, gneiss, and other hypogene rocks, which seem as if set in a sandstone frame.* The beds of the Old Red Sandstone constituting this frame may once perhaps have extended continuously over the entire Grampians before the upheaval of that mountain range, for one band of the sandstone follows the course of the Moray Frith far into the interior of the great Caledonian valley; and detached hills and island-like patches occur in several parts of the interior, capping some of the higher summits in Sutherlandshire, and appearing in Murrayshire like oases among the granite rocks of Strathspey. On the western coast of Ross-shire, the Old Red forms those three immense insulated hills before described (p. 140.), where beds of horizontal sandstone, 3000 feet high, rest unconformably on a base of gneiss, attesting the vast denudation which has taken place.

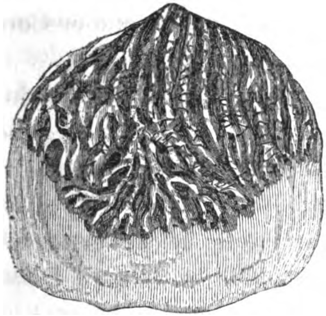
But in order to observe the uppermost part of the Old Red, we must travel south of the Grampians, and examine its junction with the bottom of the Carboniferous series in Fifeshire. This

* The Old Red Sandstone, by Hugh Miller, 1841.

upper member may be seen in Dura Den, south of Cupar, to consist of a belt of yellow sandstone, in which Dr. Fleming first discovered scales of *Holoptychus*, and in which lately a species of fish of the genus *Pterichthys* has been met with. (For genus, see Fig. 333.)

The beds next below the yellow sandstone are well seen in the large zone of Old Red which skirts the southern flank of the Grampians from Stonehaven to the Frith of Clyde. It there forms, together with trap, the Sidlaw Hills and the strata of the valley of Strathmore. A section of this region has been already given, extending from the foot of the Grampians in Forfarshire to the sea at Arbroath, a distance of about 20 miles, where the entire mass of strata are several thousand feet thick, and may be divided into three principal masses: 1st, and uppermost, red and mottled marls, cornstone and sandstone (Nos. 1 and 2. of the Section, p. 103.); 2d, Conglomerate, often of vast thickness (No. 3., ibid.); 3d, Tilestones and paving stone, highly micaceous, and containing a slight admixture of carbonate of lime (No. 4., ibid.). In the first of these divisions a gigantic species of fish of the genus *Holoptychus* has been found at Clashbinnie near Perth. Some scales have been seen which measured 3 inches in length by 2½ in breadth. At the top of the third or lowest

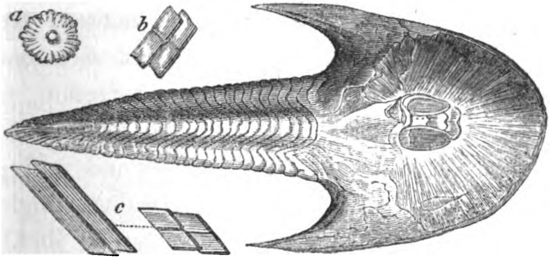
Fig. 331.



Scale of *Holoptychus nobilissimus*; Agas. Clashbinnie. nat. size.

division, or immediately under the conglomerate (No. 3. p. 103.), have been found some remarkable crustaceans and fish of the genus named by M. Agassiz, *Cephalaspis*, or "buckler-headed," from the extraordinary shield which covers the head, and which has often been mistaken for that of a trilobite, of the division *Asaphus*. (See Fig. 355. p. 168.)

Fig. 332.



Cephalaspis Lyellii, Agass. Length 6¾ inches.

This figure is from a specimen now in my collection, which I procured at Glammiss, in Forfarshire; see other figures, Agassiz, vol. ii. Tab. 1. *a.* & 1. *b.*

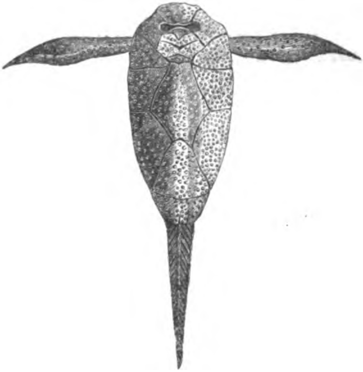
a, one of the peculiar scales with which the head is covered when perfect. These scales are generally removed, as in the specimen above figured..

b, *c*, scales from different parts of the body and tail.

Species of the same genus are considered in England as characteristic of the second or Cornstone division (p. 146.).

The lower division of the Old Red, abounding in grey slaty sandstones, is most largely developed in the north of Scotland, as in Caithness and Cromarty, where ichthyolites abound. The fish, which are of peculiar forms, belong to the new genera *Pterichthys* (Fig. 333.), *Coccosteus*, *Diplopterus*, *Dipterus*, *Cheiracanthus*, and others of Agassiz.

Fig. 333.



Pterichthys, Agassiz, upper side showing mouth; as restored by H. Miller.*

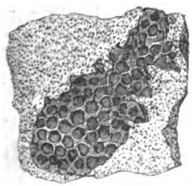
Five species of *Pterichthys* have been found in the lower division of the Old Red. The winglike appendages, whence the genus is named, were

* Plate 1. fig. 1. Mr. M.'s description of the fish is most graphic and correct.

first supposed by Mr. Miller to be paddles, like those of the turtle; but Agassiz regards them as weapons of defence, like the occipital spines of the river Bull-head (*Cottus gobio*, Linn.); and considers the tail to have been the only organ of motion. The genera *Dipterus* and *Diplopterus* are so named, because their two dorsal fins are so placed as to front the anal and ventral fins, so as to appear like two pairs of wings. They have bony enamelled scales.

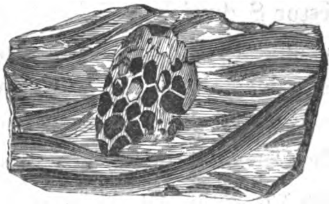
In Forfarshire the lower beds of "the Old Red" are very generally characterized by the remains of what seem to be plants or fucoids; and these are frequently accompanied, both in the grey sandstones and in the associated shales, with groups of hexagonal, or nearly hexagonal markings, which consist of small flattened carbonaceous bodies, placed in a slight depression of the

Fig. 334.



Eggs of gasteropodous mollusk?.
Lower beds of Old Red, Ley's Mill, Forfarshire.

Fig. 335.



Fucoids and eggs of gasteropodous mollusk?.
Lower Old Red, Fife.

sand or shale. (See Figs. 334. and 335.) They closely resemble in form the spawn of the recent Natica (see Fig. 336.), in which the eggs are

Fig. 336.

Fragment of spawn of British species of *Natica*.

arranged in a thin layer of sand, and seem to have acquired a polygonal form by pressing against each other. The substance of the egg, if fossilized, might give rise to small pellicles of carbonaceous matter.

These fossils I have met with, both to the north of Strathmore, in the vertical shale beneath the conglomerate, and in the same beds in the Sidlaw hills, at all the points where fig. 4. is introduced in the section, p. 103.

South of Devon and Cornwall. — A great change has lately been effected in the classification of the slaty and calciferous strata of South Devon and Cornwall, a large portion of the beds, formerly referred to the transition or primary fossiliferous series, having been found to belong in reality to the period of the Old Red Sandstone. For this reform we are indebted to the labours of Professor Sedgwick and Mr. Murchison, assisted by a suggestion of Mr. Lonsdale, who, first in 1837, examined the South Devonshire fossils, and perceived that some of them approached to those of the Carboniferous group, others to those of Siluria, while many could not be assigned to either system, the whole taken together exhibiting a peculiar and intermediate character. The true place, however, in the geological series of these slate-rocks and limestones of South Devon could not have been assigned with accuracy, if Messrs.

Sedgwick and Murchison had not previously, in 1836 and 1837, discovered that the culmiferous or anthracitic shales of North Devon belonged to the Coal, and not, as preceding observers had imagined, to the transition period.

As the strata of South Devon now under consideration are far richer in organic remains than the sandstone of contemporaneous date in Herefordshire and Scotland, the new name of the "Devonian system" has been proposed for that of Old Red Sandstone.

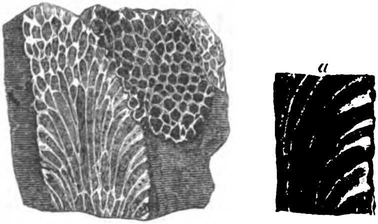
The rocks of this group consist, in great part, of green chloritic slates, alternating with hard quartzose slates and sandstones. Here and there are calcareous slates and some blue crystalline limestone, and in some divisions conglomerates, passing into red sandstone.

The link supplied by the whole assemblage of imbedded fossils, connecting as it does the palæontology of the Silurian and Carboniferous groups, is one of very high theoretical interest, and equally striking, whether we regard the genera of corals or shells. Yet the entire series, taken as a whole, is specifically distinct from the type of fossils of the antecedent or posterior formations.

Among the more abundant corals, we find the genera *Favosites* and *Cyathophyllum*, common on the one hand to the Mountain limestone, and on

the other to the Silurian system. But several even of the *species* are common to the Devonian and Silurian groups (see p. 169.), as for example, *Favosites polymorpha* (Fig. 337.), very abundant in South Devon.

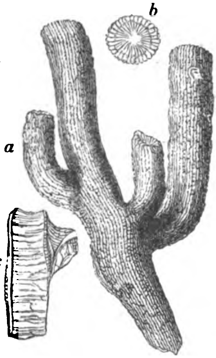
Fig. 337.



Favosites polymorpha, Goldf., S. Devon. From a polished specimen.
a. portion of the same, magnified to show the pores.

The *Cyathophyllum cæspitosum* (Fig. 338.) and *Porites pyriformis* (Fig. 358. p. 169.) are more peculiarly characteristic of the Devonian rocks.

Fig. 338.

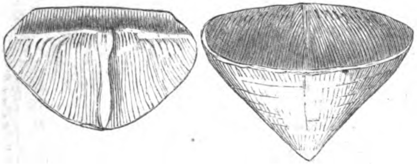


a Cyathophyllum cæspitosum, Goldf., Plymouth.
b. a terminal star.
c. vertical section exhibiting transverse plates, and part of another branch.

In regard to the shells, all the Brachiopodous genera such as *Terebratula*, *Orthis*, *Spirifer*, *Atrypa*, and *Producta*, which are found in the Mountain Limestone, occur, together with those of the Silurian system, except the *Pentamerus*. Some forms, however, seem exclusively Devonian, as for example,

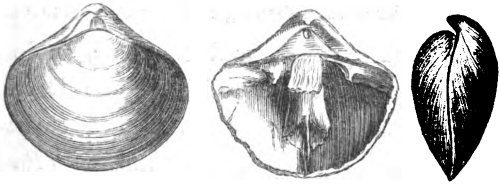
Calceola sandalina (Fig. 339.) and *Strygocephalus Burtini* (Fig. 340.), which have been met with

b Fig. 339. a



Calceola sandalina, Lam. Eifel; also South Devon.
a. both valves united. *b.* inner side of opercular valve.

a Fig. 340. c b

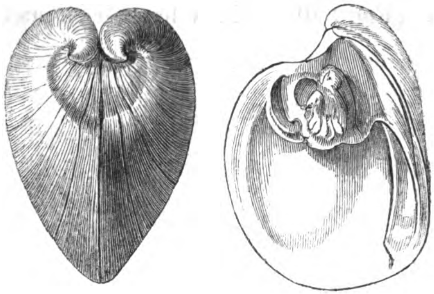


Strygocephalus Burtini. (*Terebratula porrecta*, Sow.) Eifel; also S. Devon.
a. valves united. *b.* side view of same. *c.* interior of larger valve, showing thick partition, and thinner one continued from it.

both in the Eifel, in Germany, and in Devonshire, in the very lowest Devonian beds.

Among the peculiar lamelli-branchiate bivalves, also common to Devonshire and the Eifel, we find *Megalodon cucullatus* (Fig. 341.). Several spinal univalves are abundant, among which are two or three species of *Turritella* and *Euomphalus*. Among the Cephalopoda we find *Bellerophon* and *Orthoceras*, as in the Silurian and

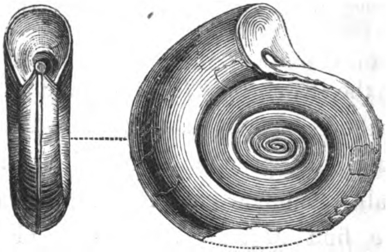
a Fig. 341. b



Megalodon cucullatus, Sow. Eifel; also Bradley, S. Devon.
a. the valves united.
b. interior of valve showing the large cardinal tooth.

Carboniferous groups, and *Goniatite*, as in the Carboniferous. In some of the upper Devonian beds, a shell, resembling a flattened *Goniatite*, occurs, called *Clymenia*, by Munster (*Endosiphonites*, Ansted.*).

Fig. 342.



Clymenia linearis, Munster. (*Endosiphonites carinatus*, Ansted.) Cornwall.

* Camb. Phil. Trans., vol. vi. pl. 8. fig. 2. This shell was figured in the first edition, as a fossil of the Cambrian strata, to which Professor Sedgwick had referred it, before adopting the new classification of the Cornish slates.

A peculiar form of Trilobite, called *Brontes flabellifer* (Fig. 343.), is found in the Devonian strata of the Eifel and in South Devon.

Fig. 343.

Brontes flabellifer, Goldf. Eifel; also S. Devon.

For determining the true equivalents of the Devonian group in the Rhenish provinces and adjacent parts of Germany, we are indebted to the labours of Professor Sedgwick and Mr. Murchison, in 1839, from which it appears that rocks of that age emerge from beneath the coal-field of Westphalia, and are also found in troughs among the Silurian rocks in Nassau. Many of the limestones, particularly those on the river Lahn, are identical, both in structure and in coralline remains, with the beautiful marbles of Babbacombe, Torquay, and Plymouth.

The limestones of the Eifel, long ago celebrated

for their fossils, and which lie in a basin supported by Silurian rocks, are found to be referable to the lower part of the Devonian system. In Russia, also, Messrs. Murchison and De Verneuil have shown (1840) that the "Old Red" group occupies a wide area south from St. Petersburgh. It was formerly supposed to be the New Red Sandstone, on account of its saliferous and gypseous beds, but it is now proved to be the Old Red by containing ichthyolites of genera which characterize this group in the British Isles, as, for example, *Holoptychus*, *Coccosteus*, *Diplopterus*, &c.*

* See Proceedings of Geol. Soc., and the anniversary speech of Dr. Buckland, P G. S., for 1841.

CHAPTER XXVI.

PRIMARY FOSSILIFEROUS STRATA.

Primary Fossiliferous or Transition Strata — Term "Grauwacké" — Silurian Group — Upper Silurian and Fossils — Lower Silurian and Fossils — Trilobites — Graptolites — Orthocerata — Occasional horizontality of Silurian Strata — Cambrian Group — Endosiphonite.

We have now arrived in the descending order at those more ancients edimentary rocks, which I have called the Primary Fossiliferous (see vol. I. p. 193.), and to which Werner first gave the name of Transition, for reasons fully explained and discussed in the 8th chapter. Many geologists have also applied to these older strata the general name of "grauwacké," by which the German miners designate a variety of quartzose sandstone, or an aggregate of small fragments of quartz, flinty-slate (or Lydian stone), and clay-slate cemented together by argillaceous matter. But by far too much importance has been attached to this kind of rock, as if it were peculiar to a certain epoch in the earth's history, whereas a similar sandstone or grit is not only found sometimes in the Old Red, and in the millstone grit of the Coal, and in certain Cretaceous formations of the Alps — but even in some tertiary deposits.

In England, the Old Red sandstone has been generally regarded as the base of the secondary

series; but by some writers on the Continent, the Old Red and Coal formations have been classed as the upper members of the Transition series, an arrangement adopted by Dr. Buckland, in his late Bridgewater Treatise. This classification, however, requires us to draw a strong line of demarcation between the Coal and the lower New Red sandstone group, which now that the fossils of these two groups are ascertained to be very analogous, becomes, perhaps, a more arbitrary division than that which separates the Old Red from the uppermost of the primary fossiliferous strata.

Professor Sedgwick and Mr. Murchison have lately proposed to subdivide all the English sedimentary strata below the Old Red sandstone into two leading groups, the upper of which may be termed the Silurian, and the inferior the Cambrian system. Mr. Murchison has applied the name of Silurian to the newer group, because these rocks may be best studied in that part of England and Wales which was included in the ancient British kingdom of the Silures. In his excellent work on the "Silurian System," he has designated the four principal subdivisions of this group as the Ludlow, Wenlock, Caradoc, and Llandeilo rocks, indicating thereby the places where the prevailing characters of each formation are most perfectly exhibited. The following Table explains the succession of these deposits.

UPPER SILURIAN ROCKS.

		Prevailing Lithological Characters.	Thickness.	Organic Remains.
1. Ludlow formation.	Upper Ludlow.	Micaceous grey sandstone.	2000 Feet.	Mollusca marine, of almost every order, the Brachiopoda most abundant. Serpula, Corals, Sauroid fish, Fuci.
	Aymestry limestone.	Argillaceous limestone.		
	Lower Ludlow.	Shale, with concretions of limestone.		
2. Wenlock formation.	Wenlock limestone.	Concretionary limestone.	1800 Feet.	Marine mollusca of various orders as before. Crustaceans of the Trilobite family. No vertebrata or plants.
	Wenlock shale.	Argillaceous shale.		

LOWER SILURIAN ROCKS.

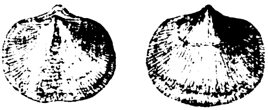
3. Caradoc formation.	Caradoc sandstones.	Flags of shelly limestone and sandstone, thick bedded white freestone.	2500 Feet.	Crinoidea, Corals, Mollusca, chiefly Brachiopoda, Trilobites.
4. Landeilo formation.	Llandeilo flags.	Dark coloured calcareous flags.	1200 Feet.	Mollusca, Trilobites.

UPPER SILURIAN ROCKS.

Ludlow formation. — This member of the upper Silurian group, as will be seen by the above table, is of great thickness, and subdivided into three parts. Each of these may be distinguished near the town of Ludlow, and at other places in Shropshire and Herefordshire, by peculiar organic remains.

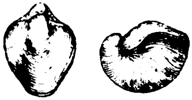
1. *Upper Ludlow.* — The uppermost division, called the Upper Ludlow, consists of grey calcareous sandstone, decomposing into soft mud, and contains, among other shells, the *Lingula cornea*, which is common to it and the lowest, or tilestone beds of the Old Red. But the *Orthis orbicularis*

Fig. 344.



Orthis orbicularis, J. Sow. Delbury. (*Strophomene orbicularis.*)

Fig. 345.



Terebratula navicula, J. Sow. Ludlow; also in Aymestry limestone.

is peculiar to the Upper Ludlow, and very common; and the lowest or mud-stone beds, are loaded for a thickness of 30 feet with *Terebratula navicula* (Fig. 345.), in vast numbers. Among the cephalopodous mollusca occur the genera *Bellerophon* and *Orthoceras*, and in the crustacea the *Homalonotus* (Fig. 353.). A coral called *Favosites*

polymorpha, Goldf. (Fig. 337. p. 154.) is found both in this subdivision and in the Devonian system. But the most remarkable fossils of this formation are the scales, spines (*Ichthyodorulites*), jaws, and teeth of fish of the genera *Onchus*, *Plectrodus* and others. As these are the oldest remains of vertebrated animals yet known to geologists, it is worthy of notice that they belong to a family of fishes of a high or very perfect organization.

Among the fossil shells are species of *Producta* (*Leptæna*), *Orthis*, *Terebratula*, *Avicula*, *Trochus*, *Orthoceras*, *Bellerophon*, and others.*

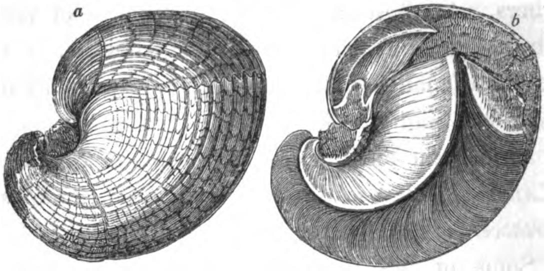
Some of the Upper Ludlow sandstones are ripple-marked, thus affording evidence of gradual deposition; and the same may be said of the accompanying fine argillaceous shales which are of great thickness, and have been provincially named "mudstones." In these shales many zoophytes are found enveloped in an erect position, having evidently become fossil on the spots where they grew at the bottom of the sea. The facility with which these rocks, when exposed to the weather, are resolved into mud, proves that notwithstanding their antiquity, they are nearly in the state in which they were first thrown down at the bottom of the sea.

2. *Aymestry limestone.* — The next group is a

* Murchison, Silurian System, p. 198, 199.

subcrystalline and argillaceous limestone, which is in some places 50 feet thick and distinguished around Aymestry by the abundance of *Pentamerus Knightii*, Sow. (Fig. 346.), also found in the Lower

Fig. 346.



Pentamerus Knightii, Sow. Aymestry.

a. view of both valves united.

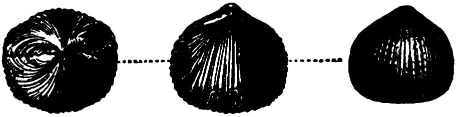
b. longitudinal section through both valves, showing the central plate or septum; half nat. size.

Ludlow. This genus of Brachiopoda has only been found in the Silurian strata. The name was derived from πεντε, *pente*, five, and μερος, *meros*, a part, because both valves are divided by a central septum, making four chambers, and in one valve the septum itself contains a small chamber, making five; but neither the structure of this shell, nor the connection of the animal with its several parts, are as yet understood.

Three other abundant shells in this limestone are, 1st, *Terebratula Wilsoni*, Sow. (Fig. 347.), which is also common to the Lower Ludlow and Wenlock limestone; 2d, *Atrypa affinis* (Fig. 348.),

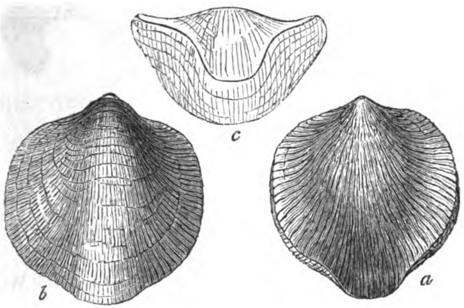
which has a very wide range, being found in every part of the Silurian system, except the Llandeilo flags; and 3dly, *Lingula Lewisii* (Fig. 349.).

Fig. 347.



Terebratula Wilsoni, Sow. Aymestry.

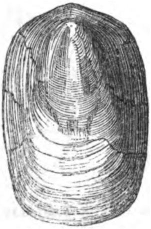
Fig. 348.



Atrypa affinis, Sow. (*Terebratula affinis*, Min. Con.) Aymestry.

a. upper valve. *b.* lower.
c. anterior margin of the valves.

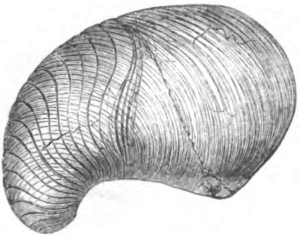
Fig. 349.



Lingula Lewisii, J. Sow. Abberley Hills.

3. *Lower Ludlow shale.* — A dark grey argillaceous deposit, containing, among other fossils, the new genera of chambered shells, *Phragmoceras* and *Lituites* of Broderip. (See Figs. 350, 351.) The latter is partly straight and partly convuluted, nearly as in Spirula.

Fig. 350.



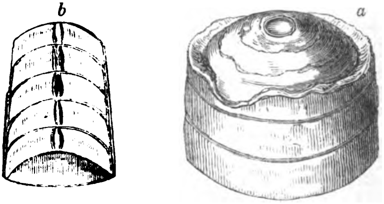
Phragmoceras ventricosum, J. Sow. (*Orthoceras ventricosum*, Stein.) Aymestry; ½ nat. size.

Fig. 351.

Lituites giganteus, J. Sow; near Ludlow; also in the Aymestry and Wenlock limestones; ½ nat. size.

The *Orthoceras Ludense* (Fig. 352.), as well as the shell last mentioned, is peculiar to this member of the series. The *Homalonotus delphinoce-*

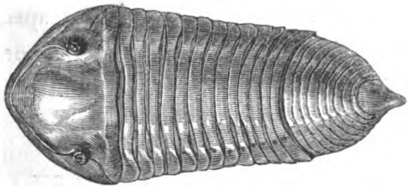
Fig. 352.



a. fragment of *Orthoceras Ludense*, J. Sow.
b. polished section, showing siphuncle. Ludlow.

phalus (Fig. 353.) is common to this division and to the Wenlock limestone. This crustacean belongs

Fig. 353.



Homalonotus delphinocephalus, König.* Dudley Castle; ½ nat. size.

to a group of trilobites which has been met with in the Silurian rocks only, and in which the tripartite character of the dorsal crust is almost lost.

A species of *Graptolite* (Fig. 364. p. 173.), a genus which has not yet been met with in strata newer than the Silurian, makes its appearance in the Lower Ludlow.

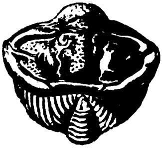
Wenlock formation. — We next come to the Wenlock formation, which has been divided (see Table, p. 161.) into

1. Wenlock limestone, formerly well known to collectors by the name of the Dudley limestone, which forms a continuous ridge, ranging for about 20 miles from S.W. to N.E., about a mile distant from the nearly parallel escarpment of the Aymestry limestone. The prominence of this rock in

* Silurian System, pl. 7. bis. fig. 1. b.

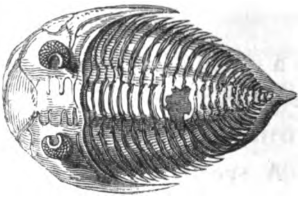
Shropshire, like that of Aymestry, is due to its solidity, and to the softness of the shales above and below. It is divided into large concretional masses of pure limestone, and abounds in trilobites, among which the prevailing species are *Asaphus caudatus* (Fig. 355.) and *Calymene Blumenbachii.* The latter is often found coiled up like a wood-louse (see Fig. 354.).

Fig. 354.



Calymene Blumenbachii, Brongniart, commonly called "Dudley trilobite." Also in L. Ludlow & Aym. lime.

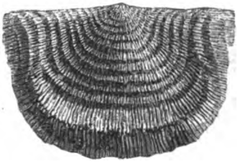
Fig. 355.



Asaphus caudatus, Brong., Ludlow; also in Aym. lime., L. Ludlow, and Wen. shale.

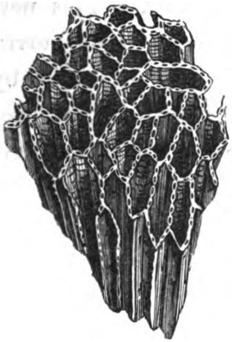
Producta depressa, Sow., is common in this rock, but also ranges through the Lower Ludlow, Wenlock shale, and Caradoc Sandstone.

Fig. 356.



Producta depressa (Syn. *Leptæna depressa*), Wenlock.

Fig. 357.



Catenipora escharoides.

Among the corals in which this formation is very rich, the *Catenipora escharoides*, Lam. (Fig. 357.), may be pointed out as one very easily recognized, and widely spread in Europe, and not yet found in any group above the Silurian, through all parts of which it ranges, from the Aymestry limestone to the bottom of the series.

Another coral, the *Porites pyriformis*, is also met with in profusion; but the same species, as before stated, is common to the Devonian rocks.

Fig. 358.

Porites pyriformis, Ehren. Wenlock. Also in Aymestry limestone, L. Ludlow, and Wen. shale.
a. Vertical section, showing transverse lamellæ.

Fig. 359.

a. Cystiphyllum Siluriense, Lonsd. Wenlock.
b. Section of portion showing cells.

Cystiphllyum Siluriense (Fig. 359.) is a species peculiar to the Wenlock limestone. This new genus, the name of which is derived from κυστις, a *bladder*, and φυλλον, a *leaf*, was instituted by Mr. Lonsdale for corals of the Silurian and Devonian groups. It is composed of small bladder-like cells (see Fig. 359. *b*.).

2. The Wenlock Shale, which exceeds 700 feet in thickness, contains many species of Brachiopoda, such as a small variety of the *Lingula Lewisii* (Fig. 349.), and the *Atrypa affinis* (Fig. 348.) before mentioned, and it will be seen that several other fossils before enumerated range into this shale.

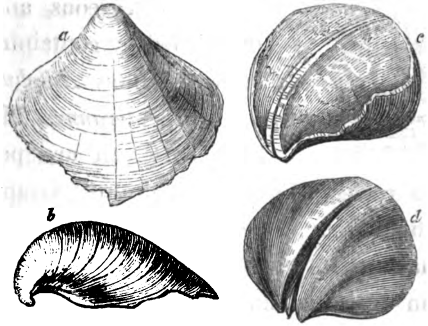
LOWER SILURIAN ROCKS.

The lower Silurian rocks have been subdivided into two portions.

1. The Caradoc sandstone, which abuts against the trappean chain called the Caradoc Hills, in Shropshire. Its thickness is estimated at 2500 ft., and the larger proportion of its fossils are specifically distinct from those of the upper Silurian rocks. Among them we find many trilobites and shells of the genera *Orthoceras*, *Nautilus*, and *Bellerophon*; and among the Brachiopoda the *Pentamerus lævis* (Fig. 360.), which is very abundant and peculiar to this bed; also *Orthis grandis* (Fig. 361.), and a fossil of well-defined form, but of which the class

is not yet determined by zoologists, *Tentaculites scalaris*, Schlot (Fig. 362.).

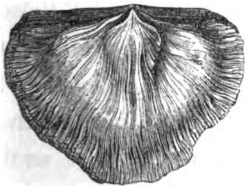
Fig. 360.



Pentamerus lævis, Sow. Caradoc Sandstone

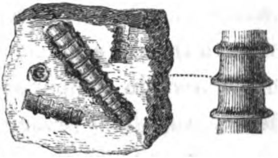
a. b. Views of the shell itself, from figures in Murchison's Sil. Syst. *c.* Cast with portion of shell remaining, and with the hollow of the central septum filled with spar. *d.* Internal cast of a valve, the space once occupied by the septum being represented by a hollow in which is seen a cast of the chamber within the septum.

Fig. 361.



Cast of *Orthis grandis*, J. Sow. Horderley; two thirds of nat. size.

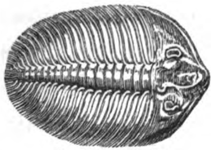
Fig. 362.



Tentaculites scalaris, Schlot. Eastnor Park; nat. size, and magnified.

2. The *Llandeilo flags*, so named from a town in Caermarthenshire, form the base of the Silurian system, consisting of dark-coloured micaceous grit, frequently calcareous, and distinguished by containing the large trilobites *Asaphus Buchii* and *A. tyrannus*, Murch., both of which are peculiar to these rocks. Several species of Graptolites (Fig. 364.) occur in these beds.

Fig. 363.



Asaphus Buchii, Brong. Caermarthen; $\frac{1}{4}$th nat. size.

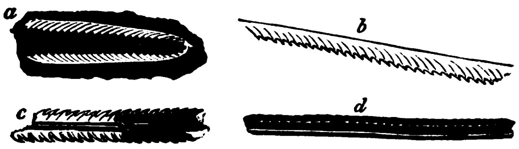
No land plants seem yet to have been discovered in strata which can be unequivocally demonstrated to belong to the Silurian period. But we learn from Mr. Conrad that, in North America, both in the highest and lowest members of the series, marine plants, or fucoids, have been discovered.

From the absence of all terrestrial vegetation and freshwater shells some geologists have inferred that a small extent of dry land existed at the remote periods now under consideration. But if we colour on a map of the globe those spots over which the Silurian strata have been hitherto traced, and consider the insignificance of their extent in comparison with the surface of the planet, we shall perceive the rashness of such generalizations.

In Norway and Sweden the Silurian strata

extend over a wide area, and so much resemble those of England in lithological character and fossils, that they will probably be found to be divisible into similar groups. They are composed of large deposits of sandstone, which is sometimes found at the base of the system, resting on gneiss and calcareous rocks, with orthocerata and corals; the chain-coral (Fig. 357.), before mentioned, being very conspicuous; also fine bituminous shales containing graptolites (Fig. 364.).

Fig. 364.



a. b. *Graptolithus Murchisonii*, Beck; Christiania, Norway; also in Lower Silurian, England.
c. *G. foliaceus*, south of Sweden; also Llandeilo flags, England.
d. *G. Ludensis*, south of Sweden; Upper Silurian, in England.

These bodies, which I collected both in the higher and lower shales of the Silurian system in Sweden and Norway, are supposed by Dr. Beck, of Copenhagen, to be fossil zoophytes, related to the *Pennatula*, of which the living animals inhabit mud and slimy sediment.

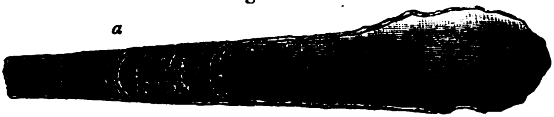
In the limestones of Lake Michigan, in North America, examined by Dr. Bigsby, and other regions bordering the great Canadian lakes, and

along the northern coast of the Gulf of St. Lawrence, surveyed by Captain Bayfield, chain-corals and trilobites are also found, and from their fossils generally they have for many years been referred to the transition period. In the state of New York also the labours of Messrs. Hall and Conrad have shown that between Lake Ontario and the Mohawk river the lower Silurian rocks are found; and further south the upper members of that series appear, being in their turn covered, on the borders of Pennsylvania, by the Old Red Sandstone, containing scales of *Holoptychus*, like those before described. (See Fig. 331. p. 149.)

Certain orthocerata, from Lake Huron, have a very peculiar structure. The siphuncle is very large, and has a tube running through its whole length, from the outside of which radii set off in verticillations extending to the inner wall of the syphon, these verticillations corresponding in number to the chambers of the shell. Mr. Stokes, who has described this division of orthoceratites, has formed them into a distinct genus, for which he has adopted the name of *Actinoceras*, proposed by Professor Bronn.* The *Actinoceras* was not known as a British fossil, until lately discovered in Silurian strata at Castle Espie, in the county of Down, in Ireland. (See Figs. 365, 366.)

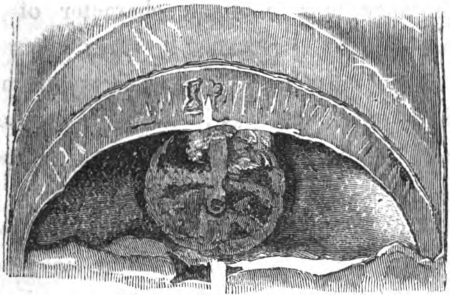
* See Trans. Geol. Soc., 2d series, vol. v. part 3. p. 708.

Fig. 365.



Actinoceras Simmsii, Stokes.
County of Down, Ireland. Length of original 2 feet.

Fig. 366.



A. Simmsii, portion of the shell at *a*, Fig. 365., natural size, showing the tube and its radii within the siphuncle.

Silurian strata occasionally horizontal.—The Silurian strata throughout a large part of the province of Skaraborg, in the south of Sweden, are perfectly horizontal; the different subordinate formations of sandstone, shale, and limestone, occurring at corresponding heights in hills many leagues distant from each other, with the same mineral characters and organic remains. It is clear that they have never been disturbed since the time of their deposition, except by such gradual movements as those by which large areas in Sweden and Greenland are now slowly and insensibly rising above or sinking below their former

level. The ancient limestone and shale also of the Canadian lake district and the State of New York, before mentioned, are for the most part horizontal.

These facts are very important, as the more ancient rocks are usually much disturbed, and horizontality is a common character of newer strata. Similar exceptions, however, occur in regard to the more modern or tertiary formations which, in some places, as in the Alps, are not only vertical, but in a reversed position. These appearances accord best with the theory which teaches that, at all periods, some parts of the earth's crust have been convulsed by violent movements, which have been sometimes continued so long, or so often repeated, that the derangement has become excessive; while other spaces have escaped again and again, and have never once been visited by the same kind of movement. Had paroxysmal convulsions ever agitated simultaneously the entire crust of the earth, as some have imagined, the primary fossiliferous strata would nowhere have remained horizontal.

Cambrian Group.—Below the Silurian strata in the region of the Cumberland lakes, in N. Wales, and other parts of Great Britain, there is a vast thickness of stratified rocks, for the most part slaty and devoid of fossils. In some places a few organic remains are detected, but they are usually

obscure; and whether the species will prove to be sufficiently distinct to entitle the rocks containing them to rank as an independent group, may be doubted. These rocks have been called Cambrian by Professor Sedgwick, because they are largely developed in N. Wales, where they attain a thickness of several thousand yards. They are chiefly formed of slaty sandstone and conglomerate, in the midst of which is a limestone containing shells and corals, as at Bala in Merionethshire. A slaty sandstone, forming the bottom of the Cambrian system in Snowdon, contains shells of the family Brachiopoda, and a few zoophytes.

TABLE

Showing the Order of Superposition, or Chronological Succession, of the principal European Groups of Fossiliferous Strata.

Periods and Groups.		Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.		Some of the Localities where the Formation occurs.
I. Post-Pliocene Period.	A. Recent.	Marine. (*a*) Consolidated and sandy beds; (*b*), hard calcareous sandstones, inclosing corals, shells, pottery, and human skeletons; (*c*), coral limestone, consisting of corals, shells, &c.	Freshwater. (*d*) Peat, with freshwater shells, bones of land animals, human remains, and works of art; (*e*) *Travertin*, calcareous deposits from mineral springs.	*a.* Newer part of delta of Rhone, in the Mediterranean. *b.* Shore of Island of Guadaloupe. *c.* Newer part of coral reefs in Pacific, &c. *d.* Kinnordy, Forfarshire; Solway Moss. *e.* Tivoli, and other parts of Italy.
	B. Post-Pliocene.	(*a*) Clay, sand, and volcanic tuff, with shells of recent species; (*b*), limestone, with casts of recent shells. *Boulder formation*, (*c*), sand and clay, with erratics.	(*d*) Sand, clay, and lignites, with shells and fish scales. *Shell marl* of Scotland (*e*), with shells and freshwater plants, and masses of solid limestone. *Loess of the Rhine.* (*f*) Silt, with land and freshwater shells.	*a.* Ischia. *b.* Cuba. *c.* Scandinavia; mud cliffs of Norfolk; and Beauport, Canada. *d.* Mundesley. *e.* Bakie, Forfarshire. *f.* Valley of Rhine.
		The Post-Pliocene deposits, including the Recent, are for the most part concealed under existing seas and lakes.		

TABLE — *continued.*

Periods and Groups.		Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.		Some of the Localities where the Formation occurs.
II. Tertiary Period.	C. Newer Pliocene.	(*a*) Loam, with marine shells; (*b*), limestone and calcareous conglomerate.	(*c*) Strata of loam, sand, and gravel, with freshwater shells and bones of extinct quadrupeds.	*a.* Glasgow. *b.* Sicily. *c.* Brentford, &c., Valley of Thames.
		A large majority of the shells of recent species.		
	D. Older Pliocene.	*Norwich Crag.* — (*a*) Shelly sand and loam, with marine shells and bones of land animals. *Subapennine beds.* — (*b*) Yellow sand and blue clay.	(*c*) Sand, with freshwater shells.	*a.* Postwick, Norwich. *b.* Subapennines, Italy. *c.* Postwick, Norwich.
		Half, or more than half, the shells usually of recent species.		
	E. Miocene.	*Red Crag.* — (*a*) Red ferruginous quartzose sand, with rolled shells. *Coralline Crag.* — (*b*) White calcareous sand, passing into a soft stone, with comminuted coral and shells. *Faluns of the Loire.* — (*c*) Similar aggregates and marl. *Bordeaux beds.* — (*d*) Argillaceous and marly deposits	(*e*) Blue clay and yellow sand, with mammalian bones and freshwater shells; (*f*), beds similar to *d*, with land and freshwater shells.	*a.* Suffolk. *b.* Orford, Suffolk. *c.* Valley of the Loire, near Nantes, Angers, Tours, and Blois. *d.* Bordeaux and Dax. *e.* Upper Val d'Arno. *f.* Saucats, 12 miles south of Bordeaux.
		About one fourth of the species of shells recent.		
	F. Eocene.	*London clay.* — (*a*) Clay and sand. *Calcaire grossier.* — (*b*) Coarse limestone.	*Calcaire siliceux.* — (*c*) Siliceous limestone, siliceous millstone, green, white, and gypseous marls and gypsum.	*a.* London and Hampshire basins. *b.* Paris basin. *c.* Paris basin; Isle of Wight.
		Species of shells, almost without exception, extinct.		

TABLE — *continued.*

Periods and Groups.		Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.	Some of the Localities where the Formation occurs.
III. Secondary Period.	G. Cretaceous Group.	1. *Maestricht Beds.*—(*a*) Soft yellowish-white limestone, resembling chalk, with siliceous masses; (*b*), aggregate of corals; (*c*), *Baculite limestone* (marine).	*a.* St. Peter's Mount, Maestricht; Ciply, near Mons. *b.* Faxoe, Denmark. *c.* Valognes, Normandy.
		2. *Chalk with flints* (marine).	North and South Downs, and parts of the intervening Weald of Kent, Surrey, and Sussex. Yorkshire; North of Ireland. Beauvais, France.
		3. Chalk without flints, and chalk-marl (marine).	
		4. *Upper green sand* (marine). — Marly stone, and sand with green particles; layers of calcareous sandstone.	
		5. *Gault* (marine). — Blue clay, with numerous fossils, passing into calcareous marl in the lower parts.	
		6. *Lower green sand* (marine). — Grey, yellowish, and greenish sands, ferruginous sands and sandstones, clays, cherts, and siliceous limestones.	
	H. Wealden Group.	1. *Weald Clay* (freshwater). — Clay for the most part without intermixture of calcareous matter, sometimes including thin beds of sand and shelly limestone.	1, 2. Extensively developed in the central parts of Kent, Surrey, and Sussex. 3. Isle of Purbeck, in Dorsetshire.
		2. *Hastings sands* (freshwater). — Grey, yellow, and reddish-brown sands, sandstones, clays, calcareous grits passing into limestone.	
		3. *Purbeck beds* (freshwater). — Various kinds of limestones and marls.	

TABLE — *continued.*

Periods and Groups.		Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.	Some of the Localities where the Formation occurs.
III. Secondary Period — *continued.*	I. Oolite, or Jura Limestone Group.	1. *Portland beds* (marine). — Coarse shelly limestone, fine-grained white limestone, compact limestone — all more or less of an oolitic structure; beds of chert.	Isle of Portland, Tisbury in Wiltshire, Aylesbury.
		2. *Kimmeridge clay* (marine). — Blue and greyish-yellow slaty clay, containing gypsum, bituminous slate (Kimmeridge coal).	Near Kimmeridge, on coast of Dorsetshire; Sunning Well, near Oxford.
		3. *Coral rag* (marine).—Calcareous shelly freestones, largely oolitic; coarse limestone, full of corals; yellow sands; calcareous siliceous grits.	Headington, near Oxford; Farringdon, in Berkshire; Calne and Steeple Ashton, in Wiltshire; Somersetshire.
		4. *Oxford clay* (marine). — Dark blue tenacious clay, with septaria, bituminous shale, sandy limestone (Kelloway rock), iron pyrites, gypsum.	New Malton, in Yorkshire; — Lincolnshire, Cambridgeshire, Huntingdonshire, and midland counties abundantly near Oxford; Somersetshire, Dorsetshire.
		5. (*a*) *Cornbrash* (marine).— Grey or bluish rubbly limestone, separated by layers of clay. (*b*) *Forest marble* (marine).— Calcareo-siliceous sand and gritstone; thin fissile beds of limestone, with clay partings; coarse shelly limestone.	*a*. Malmsbury, Atford, Wraxall, Chippenhall. *b*. Whichwood Forest, Oxfordshire; Frome, south-east of Bath.
		6. (*a*) *Great oolite* (marine). — White and yellow oolitic calcareous freestone, coarse shelly limestone, layers of clay.	*a*. Bath; Burford, in Oxfordshire; Bradford, in Wiltshire.

TABLE — *continued.*

Periods and Groups.		Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.	Some of the Localities where the Formation occurs.
III. Secondary Period — *continued.*	I. Oolite, or Jura Limestone Group — *continued.*	*b. Stonesfield slate.* — Oolitic limestone, with remains of land animals, birds, amphibia, plants, sea-shells.	*b.* Stonesfield, near Woodstock, Oxfordshire.
		7. *Fuller's earth clay* (marine). — Clay, containing in some places fuller's earth.	Near Bath.
		8. *Inferior oolite* (marine).— Soft freestone, sand with calcareous concretions.	Cotteswold Hills; Dundry Hill, near Bristol.
		Limestones of various qualities, clays, sands, and sandstone, containing the same fossils as those occurring in the series of the oolitic group of England, constitute the main body of the Jura chain of mountains, and cover vast tracts of country in Germany.	
	K. Lias Group.	*Lias* (marine). — Shale and sandy marlstone. Blue, white, and yellow earthy limestone, usually in thin beds, interstratified with clay, often slaty and bituminous.	Lyme Regis, in Dorsetshire, and in many parts of Somersetshire, Yorkshire. In France, as at Metz, and to a considerable extent in Germany, as in the Swabian Jura.
	L. Trias, or New Red Sandstone Group.	1. (*a*) *Keuper, or variegated marls.* — Red, grey, green, blue, and white marls, sandstones, conglomerates, and shales, containing gypsum and rock-salt. (*b*) *Bone bed.*—Dark coloured limestone with remains of peculiar fishes. (*c*) Red and green marl.	*a.* Neighbourhood of Vosges Mountains, and many parts of Wurtemberg and Westphalia, Nuremberg. *b.* Axmouth, Dorset, and Aust, Somerset. *c.* Axmouth. Warwick.
		2. *Muschelkalk* (marine). — Grey, blue, and blackish limestone, with alternating clay and marl, and with siliceous layers and nodules.	Extensively developed in Germany and France. Hitherto no beds in England have been identified with the formation.

TABLE — *continued.*

Periods and Groups.		Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studded.	Some of the Localities where the Formation occurs.
III. Secondary Period — *continued.*	L.	3. *Variegated* (*Bunter*) *sandstone.* — Red, white, blue, and green siliceo-argillaceous sandstone, often micaceous and containing gypsum and rock-salt.	Stuttgardt. Counties of Stafford, Salop, and Worcester.
	M. Magnesian Limestone Group.	1. (*a*) *Magnesian limestone* (marine). — Marl-slate, shelly limestone, variegated marls, yellow magnesian limestone. (*b*) *Dolomitic conglomerate.* — Fragments of subjacent rocks, with dolomitic cement. (*c*) *Zechstein of Germany.* — limestone; marl-slate, containing copper ore, and impressions of fish.	*a.* Nottinghamshire, Derbyshire, Yorkshire, Durham, Northumberland. *b.* Bristol. *c.* Mansfeld, in Thuringia.
		2. *Red conglomerate.*—*Rothliegendes* of the Germans.—Red Sandstones, conglomerates, and red marls.	Neighbourhood of Exeter; Mansfeld, in Thuringia.
	N. Carboniferous Group.	1. *Coal measures* (freshwater and marine). — Sandstones, grits, conglomerates, clays, with ironstone, shales, and limestone, interstratified with beds of coal.	Northumberland, Durham, Yorkshire, Lancashire, Staffordshire, Somersetshire, South Wales, Valleys of the Forth and Clyde. District of Liege, Westphalia, Silesia, Bohemia, &c.
		2. *Millstone grit.* — Coarse quartzose sandstone, sometimes used for millstones, usually devoid of coal.	South Wales and Bristol coal-fields. Yorkshire.
		3. *Mountain limestone* (marine). — Grey, compact, and crystalline limestone, abounding in lead ore in North of England, and alternating with coal measures in Scotland, containing corals and shells.	Mendip Hills, Derbyshire, Yorkshire, Durham, Northumberland, Lanarkshire, Linlithgowshire. Many parts of Ireland. North-west of Germany, Belgium, North of France.
	O.	1. Yellow sandstone.	Dura Den, Fife.

TABLE — *continued.*

Periods and Groups.		Names of the principal Members, and Mineral Nature of the Formation, in Countries where it has been most studied.	Some of the Localities where the Formation occurs.
III. Secondary Period — *continued.*	O. Old Red Sandstone, or Devonian Group.	2. Red and green marls, red sandstone, concretionary limestone called *cornstone*, conglomerate.	Herefordshire, Forfarshire.
		3. Tilestone and grey paving-stone, red and green shale, micaceous sandstone, grey sandstone, with peculiar fishes.	Sidlaw Hills, Forfarshire; Caithness, Cromarty.
		4. Green chloritic slates and sandstone, with shells and other fossils.	South Devon, Cornwall, Eifel.
		5. Blue crystalline limestone, with corals, shells, and other fossils of peculiar species, but with some common to the Carboniferous and Silurian groups.	Babbacombe, Torquay, and Plymouth, South Devon, Gerolstein, Eifel.
		N. B. Nos. 4. and 5. of this group (O) correspond in age to Nos. 1., 2., and 3.	
IV. Primary Fossiliferous Period.	P. Silurian Group.	1. *Ludlow rocks* (marine).— Argillaceous limestone, sandy shale.	Ludlow Castle, Shropshire; Aymestry and Woolhope, Herefordshire.
		2. *Wenlock limestone* (marine). — Coralline limestone and argillaceous shale, with nodules of earthy limestone.	Wenlock Edge, Shropshire, Dudley, Worcestershire.
		3. *Caradoc sandstones* (marine). — Shelly limestone and micaceous sandstone, quartzose grits, and sandy limestones.	Horderly, Shropshire; and May Hill, Gloucestershire. East flank of Wrekin and Caer Caradoc, Shropshire.
		4. *Llandeilo flags* (marine). — Calcareous flags, sandstone, and schist.	Llandrindod, near Builth, Radnorshire; Llandeilo, Caermarthenshire.
	Q.	*Cambrian group.* — Stratified rocks, older than the Silurian, but in which no assemblage of organic remains specifically distinct have as yet been determined. Professor Sedgwick has proposed the name of "Cambrian" for these formations, as being of great thickness in Wales.	

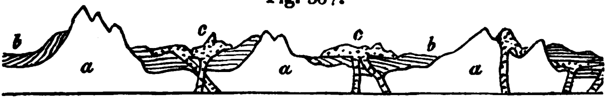
CHAPTER XXVII.

VOLCANIC ROCKS.

Trap rocks — Name, whence derived — Their igneous origin at first doubted — Their general appearance and character — Volcanic cones and craters, how formed — Mineral composition and texture of volcanic rocks — Varieties of felspar — Hornblende and augite — Isomorphism — Rocks, how to be studied — Basalt, greenstone, trachyte, porphyry, scoria, amygdaloid, lava, tuff — Alphabetical list, and explanation of names and synonyms, of volcanic rocks — Table of the analyses of minerals most abundant in the volcanic and hypogene rocks.

THE aqueous or fossiliferous rocks having now been described, we have next to examine those which may be called volcanic, in the most extended sense of that term. Suppose *a a* in the annexed

Fig. 367.



a. Hypogene formations, stratified and unstratified.
b. Aqueous formations. *c*. Volcanic rocks.

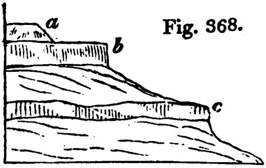
diagram, to represent the crystalline formations, such as the granitic and metamorphic; *b b* the fossiliferous strata; and *c c* the volcanic rocks.

These last are sometimes found, as was explained in the first chapter and Frontispiece, breaking through *a* and *b*, sometimes overlying both, and occasionally alternating with the strata *b b*. They also are seen, in some instances, to pass insensibly into the unstratified division of *a*, or the Plutonic rocks.

When geologists first began to examine attentively the structure of the northern and western parts of Europe, they were almost entirely ignorant of the phenomena of existing volcanos. They found certain rocks, for the most part without stratification, and of a peculiar mineral composition, to which they gave different names, such as basalt, greenstone, porphyry, and amygdaloid. All these, which were recognized as belonging to one family, were called "trap" by Bergmann, from *trappa*, Swedish for a flight of steps — a name since adopted very generally into the nomenclature of the science; for it was observed that many rocks of this class occurred in great tabular masses of unequal extent, so as to form a succession of terraces or steps on the sides of hills. This configuration appears to be derived from two causes. First, the abrupt original terminations of sheets of melted matter, which have spread, whether on the land or bottom of the sea, over a level surface. For we know, in the case of lava flowing from a volcano, that a stream, when it has ceased to flow,

and grown solid, very commonly ends in a steep slope, as at *a*, Fig. 368. But, secondly, the step-like appearance arises more frequently from the mode in which horizontal masses of igneous rock, such as *b c*, intercalated between aqueous strata, have, subsequently to their origin, been exposed, at different heights, by denudation. Such an outline, it is true, is not peculiar to trap rocks; great beds of limestone, and other hard kinds of stone, often presenting similar terraces and precipices: but these are usually on a smaller scale, or less numerous, than the volcanic *steps*, or form less decided features in the landscape, as being less distinct in structure and composition from the associated rocks.

Fig. 368.



Step-like appearance of trap.

Although the characters of trap rocks are greatly diversified, the beginner will easily learn to distinguish them as a class from the aqueous formations. Sometimes they present themselves, as already stated, in tabular masses, which are not divided into strata; sometimes in shapeless lumps and irregular cones, forming chains of small hills. Often they are seen in dikes or wall-like masses, intersecting fossiliferous beds. The rock is occasionally found divided into columns, often decomposing into balls of various sizes, from a few inches

to several feet in diameter. The decomposing surface very commonly assumes a coating of a rusty iron colour, from the oxidation of ferruginous matter, so abundant in the traps in which augite or hornblende occur; or, in the felspathic varieties of trap, it acquires a white opaque coating, from the bleaching of the mineral called felspar. On examining any of these volcanic rocks, where they have not suffered disintegration, we rarely fail to detect a crystalline arrangement in one or more of the component minerals. Sometimes the texture of the mass is cellular or porous, or we perceive that it has once been full of pores and cells, which have afterwards become filled with carbonate of lime, or other infiltrated mineral.

Most of the volcanic rocks produce a fertile soil by their disintegration. It seems that their component ingredients, silica, alumina, lime, potash, iron, and the rest, are in proportions well fitted for vegetation. As they do not effervesce with acids, a deficiency of calcareous matter might at first be suspected; but although *the carbonate* of lime is rare, except in the nodules of amygdaloids, yet it will be seen that lime sometimes enters largely into the composition of augite and hornblende. (See Table, p. 210.)

Cones and Craters. — In regions where the eruption of volcanic matter has taken place in the

open air, and where the surface has never since been subjected to great aqueous denudation, cones and craters constitute the most striking peculiarity of this class of formations. Many hundreds of these cones are seen in central France, in the ancient provinces of Auvergne, Velay, and Vivarais, where they observe, for the most part, a linear arrangement, and form chains of hills. Although

Fig. 369.

Part of the chain of extinct volcanos called the Monts Dome, Auvergne. (Scrope.)

none of the eruptions have happened within the historical era, the streams of lava may still be traced distinctly descending from many of the craters, and following the lowest levels of the existing valleys. The origin of the cone and crater-shaped hill is well understood, the growth of many having been watched during volcanic eruptions. A chasm or fissure first opens in the earth, from which great volumes of steam and other gases are evolved. The explosions are so violent as to hurl up into the air fragments of broken stone, parts of which are shivered into minute atoms. At the same time melted stone or *lava* usually

ascends through the chimney or vent by which the gases make their escape. Although extremely heavy, this lava is forced up by the expansive power of entangled gaseous fluids, chiefly steam or aqueous vapour, exactly in the same manner as water is made to boil over the edge of a vessel when steam has been generated at the bottom by heat. Large quantities of the lava are also shot up into the air, where it separates into fragments, and acquires a spongy texture by the sudden enlargement of the included gases, and thus forms *scoriæ*, other portions being reduced to an impalpable powder or dust. The showering down of the various ejected materials round the orifice of eruption gives rise to a conical mound, in which the successive envelopes of sand and scoriæ form layers, dipping on all sides from a central axis. In the mean time a hollow, called a *crater*, has been kept open in the middle of the mound by the continued passage upwards of steam and other gaseous fluids. The lava sometimes flows over the edge of the crater, and thus thickens and strengthens the sides of the cone; but sometimes it breaks it down on one side, and often it flows out from a fissure at the base of the hill (see Fig. 369.).*

* For a description and theory of active volcanos, see Principles of Geology.

Composition and nomenclature.— Before speaking of the connection between the products of modern volcanos and the rocks usually styled trappean, and before describing the external forms of both, and the manner and position in which they occur in the earth's crust, it will be desirable to treat of their mineral composition and names. The varieties most frequently spoken of are basalt, greenstone, syenitic greenstone, clinkstone, claystone, and trachyte; while those founded chiefly on peculiarities of texture, are porphyry, amygdaloid, lava, tuff, scoriæ, and pumice. It may be stated generally, that all these are mainly composed of two minerals, or families of simple minerals, *felspar* and *hornblende*; some almost entirely of hornblende, others of felspar.

These two minerals may be regarded as two groups, rather than species. Felspar, for example, may be, first, common felspar, that is to say, potash-felspar, in which the alkali is potash (see Table, p. 210.); or, secondly, albite, that is to say, soda-felspar, where the alkali is soda instead of potash; or, thirdly, Labrador-felspar (Labradorite), which differs not only in its iridescent hues, but also in its angle of fracture or cleavage, and its composition. We also read much of two other kinds, called glassy felspar and compact felspar, which, however, cannot rank as varieties of equal importance, for both the albitic and common fel-

spar appear sometimes in transparent or *glassy* crystals; and as to compact felspar, it is probably a compound of a less definite nature, sometimes containing, according to Dr. MacCulloch, both soda and potash.

The other group, or *hornblende*, consists principally of two varieties; first, hornblende, and, secondly, augite, which were once regarded as very distinct, although now some eminent mineralogists are in doubt whether they are not one and the same mineral, differing only as one crystalline form of native sulphur differs from another.

The history of the changes of opinion on this point is curious and instructive. Werner first distinguished augite from hornblende; and his proposal to separate them obtained afterwards the sanction of Haüy, Mohs, and other celebrated mineralogists. It was agreed that the form of the crystals of the two species were different, and their structure, as shown by *cleavage*, that is to say, by breaking or cleaving the mineral with a chisel, or a blow of the hammer, in the direction in which it yields most readily. It was also found by analysis that augite usually contained more lime, less alumina, and no fluoric acid; which last, though not always found in hornblende, often enters into its composition in minute quantity. In addition to these characters, it was remarked as a geological fact, that augite and hornblende are very rarely

associated together in the same rock; and that when this happened, as in some lavas of modern date, the hornblende occurs in the mass of the rock, where crystallization may have taken place more slowly, while the augite merely lines cavities where the crystals may have been produced rapidly. It was also remarked, that in the crystalline slags of furnaces, augitic forms were frequent, the hornblendic entirely absent; hence it was conjectured that hornblende might be the result of slow, and augite of rapid cooling. This view was confirmed by the fact, that Mitscherlich and Berthier were able to make augite artificially, but could never succeed in forming hornblende. Lastly, Gustavus Rose fused a mass of hornblende in a porcelain furnace, and found that it did not, on cooling, assume its previous shape, but invariably took that of augite. The same mineralogist observed certain crystals in rocks from Siberia which presented a hornblende *cleavage*, while they had the external form of augite.

If, from these data, it is inferred that the same substance may assume the crystalline forms of hornblende or augite indifferently, according to the more or less rapid cooling of the melted mass, it is nevertheless certain that the variety commonly called augite, and recognized by a peculiar crystalline form, has usually more lime in it, and less alumina, than that called hornblende, although

the quantities of these elements do not seem to be always the same. Unquestionably the facts and experiments above mentioned show the very near affinity of hornblende and augite; but even the convertibility of one into the other by melting and recrystallizing, does not perhaps demonstrate their absolute identity. For there is often some portion of the materials in a crystal which are not in perfect chemical combination with the rest. Carbonate of lime, for example, sometimes carries with it a considerable quantity of silex into its own form of crystal, the silex being mechanically mixed as sand, and yet not preventing the carbonate of lime from assuming the form proper to it. This is an extreme case, but in many others some one or more of the ingredients in a crystal may be excluded from perfect chemical union; and after fusion, when the mass recrystallizes, the same elements may combine perfectly or in new proportions, and thus a new mineral may be produced. Or some one of the gaseous elements of the atmosphere, the oxygen for example, may, when the melted matter reconsolidates, combine with some one of the component elements.

The different quantity of the impurities or refuse above alluded to, which may occur in all but the most transparent and perfect crystals, may partly explain the discordant results at which experienced chemists have arrived in their analysis of the same

mineral. For the reader will find that a mineral determined to be the same by its physical characters, crystalline form, and optical properties, has often been declared by skilful analysers to be composed of distinct elements. (See the Table at p. 210.) This disagreement seemed at first subversive of the doctrine, that there is a fixed and constant relation between the crystalline form and structure of a mineral, and its chemical composition. The apparent anomaly, however, which threatened to throw the whole science of mineralogy into confusion, was in a great degree reconciled to fixed principles by the discoveries of Professor Mitscherlich at Berlin, who ascertained that the composition of the minerals which had appeared so variable, was governed by a general law, to which he gave the name of *isomorphism* (from ισος, *isos*, equal, and μορφη, *morphe*, form.) According to this law, the ingredients of a given species of mineral are not absolutely fixed as to their kind and quality; but one ingredient may be replaced by an equivalent portion of some analogous ingredient. Thus, in augite, the lime may be in part replaced by portions of protoxide of iron, or of manganese, while the form of the crystal, and the angle of its cleavage planes, remain the same. These vicarious substitutions, however, of particular elements cannot exceed certain defined limits.

Having been led into this digression on the recent progress of mineralogy, I may here observe that the geological student must endeavour as soon as possible to familiarize himself with the characters of five at least of the most abundant simple minerals of which rocks are composed. These are, felspar, quartz, mica, hornblende, and carbonate of lime. This knowledge cannot be acquired from books, but requires personal inspection, and the aid of a teacher. It is well to accustom the eye to know the appearance of rocks under the lens. To learn to distinguish felspar from quartz is the most important step to be first aimed at. In general we may know the felspar because it can be scratched with the point of a knife, whereas the quartz, from its extreme hardness, receives no impression. But when these two minerals occur in a granular and uncrystallized state, the young geologist must not be discouraged if, after considerable practice, he often fails to distinguish them by the eye alone. If the felspar is in crystals, it is easily recognized by its cleavage: but when in grains the blow-pipe must be used, for the edges of the grains can be rounded in the flame, whereas those of *quartz* are infusible. If the geologist is desirous of distinguishing the three varieties of felspar above enumerated, or hornblende from augite, it will often be necessary to use the reflecting goniometer as a test of the angle

of cleavage, and shape of the crystal. The use of this instrument will not be found difficult.

The external characters and composition of the felspars are extremely different from those of augite or hornblende; so that the volcanic rocks in which either of these minerals decidedly predominate, are easily recognized. But there are mixtures of the two elements in every possible proportion, the mass being sometimes exclusively composed of felspar, at other times solely of augite, or, again, of both in equal quantities. Occasionally, the two extremes, and all the intermediate gradations, may be detected in one continuous mass. Nevertheless there are certain varieties or compounds which prevail so largely in nature, and preserve so much uniformity of aspect and composition, that it is useful in geology to regard them as distinct rocks, and to assign names to them, such as basalt, greenstone, trachyte, and others, already mentioned.

Basalt.— As an example of rocks in which augite greatly prevails, basalt may first be mentioned. Although we are more familiar with this term than with that of any other kind of trap, it is difficult to define it, the name having been used so vaguely. It has been very generally applied to any trap rock of a black, bluish, or leaden-grey colour, having a uniform and compact texture. Most strictly, it consists of an intimate mixture of augite, felspar, and iron, to which a mineral of an

olive green colour, called olivine, is often superadded, in distinct grains or nodular masses. The iron is usually magnetic, and is often accompanied by another metal, titanium. Augite is the predominant mineral, the felspar being in much smaller proportions. There is no doubt that many of the fine-grained and dark-coloured trap rocks, called basalt, contain hornblende in the place of augite; but this will be deemed of small importance after the remarks above made. Other minerals are occasionally found in basalt; and this rock may pass insensibly into almost any variety of trap, especially into greenstone, clinkstone, and wacké, which will be presently described.

Greenstone, or *Dolerite*, is usually defined as a granular rock, the constituent parts of which are hornblende and imperfectly crystallized felspar; the felspar being more abundant than in basalt; and the grains or crystals of the two minerals more distinct from each other. This name may also be extended to those rocks in which augite is substituted for hornblende (the dolerite of some authors), or to those in which albite replaces common felspar, forming the rock sometimes called Andesite.

Syenitic greenstone.—The highly crystalline compounds of the same two minerals, felspar and hornblende, having a granitiform texture, and with occasionally some quartz accompanying, may be called Syenitic greenstone, a rock which fre-

quently passes into ordinary trap, and as frequently into granite.

Trachyte.—A porphyritic rock of a whitish or greyish colour, composed principally of glassy felspar, with crystals of the same, generally with some hornblende and some titaniferous iron. In composition it is extremely different from basalt, this being a felspathic, as the other is an augitic, rock. It has a peculiar rough feel, whence the name τραχυς, *trachus*, rough. Some varieties of trachyte contain crystals of quartz.

Porphyry is merely a certain form of rock, very characteristic of the volcanic formations. When distinct crystals of one or more minerals are scattered through an earthy or compact base, the rock is termed a porphyry (see Fig. 370.). Thus trachyte is porphyritic; for in it, as in many modern lavas, there are crystals of felspar; but in some porphyries the crystals are of augite, olivine, or other minerals. If the base be greenstone, basalt, or pitchstone, the rock may be denominated greenstone-porphyry, pitchstone-porphyry, and so forth.

Fig. 370.

Porphyry.
White crystals of felspar in a dark base of hornblende and felspar.

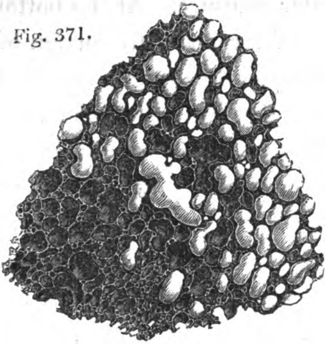
Amygdaloid. — This is also another form of ig-

neous rock, admitting of every variety of composition. It comprehends any rock in which round or almond-shaped nodules of some mineral, such as agate, calcedony, calcareous spar, or zeolite, are scattered through a base of wacké, basalt, greenstone, or other kind of trap. It derives its name from the Greek word *amygdala*, an almond. The origin of this structure cannot be doubted, for we may trace the process of its formation in modern lavas. Small pores or cells are caused by bubbles of steam and gas confined in the melted matter. After or during consolidation, these empty spaces are gradually filled up by matter separating from the mass, or infiltered by water permeating the rock. As these bubbles have been sometimes lengthened by the flow of the lava before it finally cooled, the contents of such cavities have the form of almonds. In some of the amygdaloidal traps of Scotland, where the nodules have decomposed, the empty cells are seen to have a glazed or vitreous coating, and in this respect exactly resemble scoriaceous lavas, or the slags of furnaces.

The annexed figure represents a fragment of stone taken from the upper part of a sheet of basaltic lava in Auvergne. One half is scoriaceous, the pores being perfectly empty, the other part is amygdaloidal, the pores or cells being mostly filled up with carbonate of lime, forming white kernels.

Scoriæ and *Pumice* may next be mentioned as

Fig. 371.



Scoriaceous lava in part converted into an amygdaloid.
Montagne de la Veille, Department of Puy de Dome, France.

porous rocks, produced by the action of gases on materials melted by volcanic heat. *Scoriæ* are usually of a reddish brown and black colour, and are the cinders and slags of basaltic or augitic lavas. *Pumice* is a light, spongy, fibrous substance, produced by the action of gases on trachytic and other lavas; the relation, however, of its origin to the composition of lava is not yet well understood. Von Buch says that it never occurs where only Labrador-felspar is present.

Lava.—This term has a somewhat vague signification, having been applied to all melted matter observed to flow in streams from volcanic vents. When this matter consolidates in the open air, the upper part is usually scoriaceous, and the mass becomes more and more stony as we descend, or in proportion as it has consolidated more slowly and

under greater pressure. At the bottom, however, of a stream of lava, a small portion of scoriaceous rock very frequently occurs, formed by the first thin sheet of liquid matter, which often precedes the main current, or in consequence of the contact with water in or upon the damp soil.

The more compact lavas are often porphyritic, but even the scoriaceous part sometimes contains imperfect crystals, which have been derived from some older rocks, in which the crystals pre-existed, but were not melted, as being more infusible in their nature.

Although melted matter rising in a crater, and even that which enters rents on the side of a crater, is called lava, yet this term belongs more properly to that which has flowed either in the open air or on the bed of a lake or sea. If the same fluid has not reached the surface, but has been merely injected into fissures below ground, it is called trap.

There is every variety of composition in lavas; some are trachytic, as in the Peak of Teneriffe; a great number are basaltic, as in Vesuvius and Auvergne; others are Andesitic, as those of Chili; some of the most modern in Vesuvius consist of green augite, and many of those of Etna of augite and Labrador-felspar.*

Trap tuff, volcanic tuff. — Small angular frag-

* G. Rose, Ann. des Mines, tom. 8. p. 32.

ments of the scoriæ and pumice, above mentioned, and the dust of the same, produced by volcanic explosions, form the tuffs which abound in all regions of active volcanos, where showers of these materials, together with small pieces of other rocks ejected from the crater, fall down upon the land or into the sea. Here they often become mingled with shells, and are stratified. Such tuffs are sometimes bound together by a calcareous cement, and form a stone susceptible of a beautiful polish. But even when little or no lime is present, there is a great tendency in the materials of ordinary tuffs to cohere together.

Besides the peculiarity of their composition, some tuffs, or *volcanic grits*, as they have been termed, differ from ordinary sandstones by the angularity of their grains. When the fragments are coarse, the rock is styled a volcanic *breccia*. *Tufaceous conglomerates* result from the intermixture of rolled fragments or pebbles of volcanic and other rocks with tuff.

According to Mr. Scrope, the Italian geologists confine the term *tuff*, or tufa, to felspathose mixtures, and those composed principally of pumice, using the term *peperino* for the basaltic tuffs.*

We meet occasionally with extremely compact beds of volcanic materials, interstratified with fossiliferous rocks. These may sometimes be

* Geol. Trans. vol. ii. p. 211. Second Series.

tuffs, although their density or compactness is such as to cause them to resemble many of those kinds of trap which are found in ordinary dikes. The chocolate-coloured mud, which was poured for weeks out of the crater of Graham's Island, in the Mediterranean, in 1831, must, when unmixed with other materials, have constituted a stone heavier than granite. Each cubic inch of the impalpable powder which has fallen for days through the atmosphere during some modern eruptions, has been found to weigh, without being compressed, as much as ordinary trap rocks, and to be often identical with these in mineral composition.

The fusibility of the igneous rocks generally exceeds that of other rocks, for there is much alkaline matter and lime in their composition, which serves as a flux to the large quantity of silica, which would be otherwise so refractory an ingredient.

It is remarkable that, notwithstanding the abundance of this silica, quartz is usually wanting in the volcanic rocks, or is present only as an occasional mineral, like mica. The elements of mica, as of quartz, occur in lava and trap, but the circumstances under which these rocks are formed are evidently unfavourable to the development of mica and quartz, minerals so characteristic of the hypogene formations.

It would be tedious to enumerate all the varieties of trap and lava which have been regarded by different observers as sufficiently abundant to deserve distinct names, especially as each investigator is too apt to exaggerate the importance of local varieties which happen to prevail in districts best known to him. It will be useful, however, to subjoin here, in the form of a glossary, an alphabetical list of the names and synonyms most commonly in use, with brief explanations, to which I have added a table of the analysis of the simple minerals most abundant in the volcanic and hypogene rocks.

Explanation of the names, synonyms, and mineral composition of the more abundant volcanic rocks.

AMPHIBOLITE. *See* Hornblende rock, amphibole being Haüy's name for hornblende.

AMYGDALOID. A particular form of volcanic rock; *see* p. 200.

AUGITE ROCK. A kind of basalt or greenstone, composed wholly or principally of granular augite. (*Leonhard's Mineralreichs*, 2d edition, p. 85.)

AUGITIC-PORPHYRY. Crystals of Labrador-felspar and of augite, in a green or dark grey base. (*Rose, Ann. des Mines*, tom. 8. p. 22. 1835.)

BASALT. Chiefly augite — an intimate mixture of augite and felspar with magnetic iron, olivine, &c. *See* p. 197. The yellowish green mineral called olivine, can easily be distin-

guished from yellowish felspar by its infusibility, and having no cleavage. The edges turn brown in the flame of the blow-pipe.

CLAYSTONE and CLAYSTONE-PORPHYRY. An earthy and compact stone, usually of a purplish colour, like an indurated clay; passes into hornstone; generally contains scattered crystals of felspar and sometimes of quartz.

CLINKSTONE. *Syn.* Phonolite, fissile Petrosilex; a greenish or greyish rock, having a tendency to divide into slabs and columns; hard, with clean fracture, ringing under the hammer; principally composed of compact felspar, and, according to Gmelin, of felspar and mesotype. (*Leonhard, Mineralreichs*, p. 102.) A rock much resembling clinkstone, and called by some Petrosilex, contains a considerable percentage of quartz and felspar. As both trachyte and basalt pass into clinkstone, the rock so called must be very various in composition.

COMPACT FELSPAR, which has also been called Petrosilex; the rock so called includes the hornstone of some mineralogists, is allied to clinkstone, but is harder, more compact, and translucent. It is a varying rock, of which the chemical composition is not well defined, and is perhaps the same as that of clay. (*MacCulloch's Classification of Rocks*, p. 481.) Dr. MacCulloch says, that it contains both potash and soda.

CORNEAN. A variety of claystone allied to hornstone. A fine homogeneous paste, supposed to consist of an aggregate of felspar, quartz, and hornblende, with occasionally epidote, and perhaps chlorite; it passes into compact felspar and hornstone. (*De la Beche, Geol. Trans.* second series, vol. 2. p. 3.)

DIALLAGE ROCK. *Syn.* Euphotide, Gabbro, and some Ophiolites. Compounded of felspar and diallage, sometimes with the addition of serpentine, or mica, or quartz. (*MacCulloch, ibid.* p. 648.)

DIORITE. A kind of greenstone, which see. Components, felspar and hornblende in grains. According to *Rose, Ann. des Mines*, tom. 8. p. 4., *diorite* consists of albite and hornblende.

Dioritic-porphyry. A porphyritic greenstone, composed of crystals of albite and hornblende, in a greenish or blackish base. (*Rose, ibid.* p. 10.)

Dolerite. Formerly defined as a synonym of greenstone, which see. But according to Rose (*ibid.* p. 32.), its composition is black augite and Labrador-felspar; according to Leonhard (*Mineralreichs*, &c. p. 77.), augite, Labrador-felspar, and magnetic iron.

Domite. An earthy condition of *trachyte*, found in the Puy de Dome, in Auvergne.

Euphotide. A mixture of grains of Labrador-felspar and diallage. (*Rose, ibid.* p. 19.) According to some, this rock is defined to be a mixture of augite or hornblende, and Saussurite, a mineral allied to jade. (*Allan's Mineralogy*, p. 158.) *See* Diallage rock.

Felspar-porphyry. *Syn.* Hornstone-porphyry; a base of felspar, with crystals of felspar, and crystals and grains of quartz. *See* also Hornstone.

Gabbro, *see* Diallage-rock.

Greenstone. *Syn.* Dolerite and diorite; components, hornblende and felspar, or augite and felspar in grains. See above, p. 198.

Greystone. (Graustein of Werner.) Lead grey and greenish rock, composed of felspar and augite, the felspar being more than seventy-five per cent. (*Scrope, Journ. of Sci.* No. 42. p. 221.) Greystone lavas are intermediate in composition between basaltic and trachytic lavas.

Hornblende rock. A greenstone, composed principally of granular hornblende, or augite. (*Leonhard, Mineralreichs*, &c., p. 85.)

Hornstone, Hornstone-porphyry. A kind of felspar porphyry (*Leonhard, ibid.*), with a base of hornstone, a mineral approaching near to flint, differing from compact felspar in being infusible.

Hypersthene rock, a mixture of grains of Labrador-felspar and hypersthene (*Rose, Ann. des Mines*, tom. 8. p.13.), having

the structure of syenite or granite; abundant among the traps of Sky. In a geological view, it has been called a greenstone, in which hypersthene takes the place of hornblende.

Melaphyre. A variety of black porphyry, the base being black augite with crystals of felspar; from μελας, *melas*, black.

Obsidian. Vitreous lava like melted glass, nearly allied to pitchstone.

Ophiolite, sometimes same as Diallage rock (*Leonhard*, p. 77.); sometimes a kind of serpentine.

Ophite. A green porphyritic rock, composed chiefly of hornblende, with crystals of that mineral in a base of the same, mixed with some felspar. It passes into serpentine by a mixture of talc. (*Burat's D'Aubuisson*, tom. 2. p. 63.)

Pearlstone. A volcanic rock having the lustre of mother of pearl; usually having a nodular structure; intimately related to obsidian, but less glassy.

Peperino. A form of volcanic tuff, composed of basaltic scoriæ. *See* p. 203.

Petrosilex. *See* Clinkstone and Compact Felspar.

Phonolite. *Syn.* of Clinkstone, which see.

Pitchstone; vitreous lava, less glassy than obsidian; a blackish green rock resembling glass, having a resinous lustre and appearance of pitch; composition various, usually felspar and augite; passes into basalt; occurs in veins, and in Arran forms a dike thirty feet wide, cutting through sandstone; forms the outer walls of some basaltic dikes.

Porphyry. Any rock in which detached crystals of felspar, or of one or more minerals, are diffused through a base. *See* p. 199.

Pozzolana. A kind of tuff. *See* Vol. I. p.78.

Pumice. A light, spongy, fibrous form of trachyte. *See* p.201.

Pyroxenic-porphyry, same as augitic-porphyry, pyroxene being Haüy's name for augite.

Scoriæ. *Syn.* volcanic cinders; reddish brown or black porous form of lava. *See* p.201.

Serpentine. A greenish rock, in which there is much magnesia;

usually contains diallage, which is nearly allied to the simple mineral called serpentine. Occurs sometimes, though rarely, in dikes, altering the contiguous strata; is indifferently a member of the trappean or hypogene series.

Syenitic-greenstone; composition, crystals or grains of felspar and hornblende. *See* p. 198.

Tephrine, synonymous with lava.

Toadstone. A local name in Derbyshire for a kind of wacké, which see.

Trachyte, chiefly composed of glassy felspar, with crystals of glassy felspar. *See* p. 199.

Trap tuff. *See* p. 203.

Trass. A kind of tuff or mud poured out by lake-craters during eruptions; common in the Eifel, in Germany.

Tufaceous conglomerate. *See* p. 203.

Tuff. *Syn.* Trap-tuff, volcanic tuff. *See* p. 203.

Vitreous lava. *See* Pitchstone and Obsidian.

Volcanic tuff. *See* p. 203.

Wacké. A soft and earthy variety of trap, having an argillaceous aspect. It resembles indurated clay, and when scratched, exhibits a shining streak.

Whinstone. A Scotch provincial term for greenstone and other hard trap rocks.

ANALYSIS OF MINERALS MOST ABUNDANT IN THE VOLCANIC AND HYPOGENE ROCKS.

	Silica.	Alumina.	Magnesia.	Lime.	Potash.	Soda.	Iron Oxide.	Manganese.	Remainder.
Actinolite (Bergman) - -	64·	- -	22·	- -	- -	- -	3·		
Albite (Rose) - - -	68·84	20·53	- -	a trace	- -	9·12			
—— (mean of 4 analyses) -	69·45	19·44	0·13	0·22	- -	9·95	a trace	a trace.	
Augite (Rose) - - -	53·36	- -	4·99	22·19	- -	- -	17·38	0·09	
—— (mean of 4 analyses) -	53·57	1·	11·26	20·9	- -	- -	10·75	0·67	
Carbonate of Lime (Biot) -	- -	- -	- -	56·33	- -	- -	- -	- -	43·05 C.
Chiastolite (Landgrabe) - -	68·49	30·17	4·12	- -	- -	- -	2·7	- -	0·27 W.
Chlorite (Vauquelin) - -	26·	18·5	8·	- -	- -	2·	43·		
—— (mean of 3 analyses) -	27·43	17·9	14·56	0·50	1·56	- -	30·63	- -	6·92 W.
Diallage (Klaproth) - -	60·	- -	27·5	- -	- -	- -	10·5		
—— (mean of 3 analyses) -	43·33	2·2	26·41	5·58	- -	- -	11·53	- -	8·54 W.
Epidote (Vauquelin) - -	37·	21·	- -	15·	- -	- -	24·	1·5	
Felspar, common, (Vauq.) -	62·83	17·02	- -	3·	13·	- -	1·		
—— (Rose) - - -	66·75	17·5	- -	1·25	12·	- -	0·75		
—— (mean of 7 analyses) -	64·04	18·94	- -	0·76	13·66	- -	0·74		
Garnet (Klaproth) - -	35·75	27·25	- -	- -	- -	- -	36·	0·25	
—— (Phillips) - - -	43·	16·	- -	20·	- -	- -	16·		

	Silica.	Alumina.	Magnesia.	Lime.	Potash.	Soda.	Iron Oxide.	Manganese.	Remainder.
Hornblende (Klap.) - -	42·	12·	2·25	11·	a trace	- -	30·	0·25	
——— (Bonsdorff.) -	45·69	12·18	18·79	13·85	- -	- -	7·32	0·22	1·5 F.
Hypersthene (Klaproth) -	54·25	2·25	14·	1·5	- -	- -	24·5	a trace	1· W.
Labrador-felspar (Klap.) -	55·75	26·5	- -	11·	- -	4·	1·25	- -	0·5 W.
Leucite (Klap.) - - -	53·75	24·62	- -	- -	21·35				
Mesotype (Gehlen) - -	54·46	19·70	- -	1·61	- -	15·09	- -	- -	9·83 W.
Mica (Klaproth) - - -	42·5	11·5	9·	- -	10·	- -	22·	2·	
—— (Vauquelin) - - -	50·	35·	- -	1·33	- -	- -	7·		
—— (mean of 3 analyses) -	45·83	22·58	- -	- -	11·08	- -	14·	1·45	
Olivine (Klaproth) - -	50·	- -	38·5	- -	- -	- -	12·		
Schorl or Tourmaline (Gmelin)	35·48	34·75	4·68	- -	0·48	1·75	17·44	1·89	4·02 B.
—— (mean of 6 analyses) -	36·03	35·82	4·44	0·28	0·71	1·96	13·71	1·62	
Serpentine (Hisinger) - -	43·07	0·25	40·37	0·5	- -	- -	1·17	- -	12·45 W.
——— (mean of 5 analyses)	37·29	4·97	36·8	2·89	- -	- -	3·14	- -	12·77 W.
Steatite (Vauquelin) - -	64·	- -	22·	- -	- -	- -	3·	- -	5· W.
——(mean of 3 anal. by Klap.)	48·3	6·18	26·65	- -	- -	- -	2·	- -	9·5 W.
Talc (Klaproth) - - -	61·75	- -	30·5	- -	2·75	- -	2·5		

In the last column of the above Table, the letters B. C. F. W. represent Boracic acid, Carbonic acid, Fluoric acid, and Water.

CHAPTER XXVIII.

VOLCANIC ROCKS — *continued.*

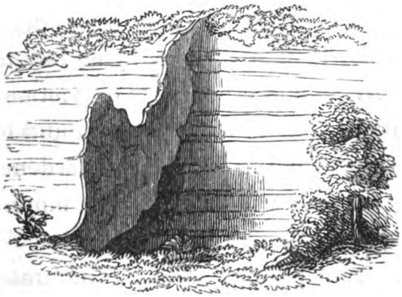
Trap dikes — sometimes project — sometimes leave fissures vacant by decomposition — Branches and veins of trap — Dikes more crystalline in the centre—Foreign fragments of rock imbedded — Strata altered at or near the contact — Obliteration of organic remains — Conversion of chalk into marble — and of coal into coke—Inequality in the modifying influence of dikes — Trap interposed between strata — Columnar and globular structure — Relation of trappean rocks to the products of active volcanos — Submarine lava and ejected matter corresponds generally to ancient trap.

HAVING in the last chapter spoken of the composition and mineral characters of volcanic rocks, I shall next describe the manner and position in which they occur in the earth's crust, and their external forms. Now the leading varieties, such as basalt, greenstone, trachyte, porphyry, and the rest are found sometimes in dikes penetrating stratified and unstratified formations, sometimes in shapeless masses protruding through or overlying them, or in horizontal sheets intercalated between strata.

Volcanic dikes. — Fissures have already been spoken of as occurring in all kinds of rocks, some a few feet, others many yards in width, and often

filled up with earth or angular pieces of stone, or with sand and pebbles. Instead of such materials, suppose a quantity of melted stone to be driven or injected into an open rent, and there consolidated, we have then a tabular mass resembling a wall, and called a trap dike. It is not uncommon to find such dikes passing through strata of soft materials, such as tuff or shale, which, being more perishable than the trap, are often washed away by the sea, rivers, or rain, in which case the dike stands prominently out in the face of precipices, or on the level surface of a country. (See the annexed figure.) *

Fig. 372.



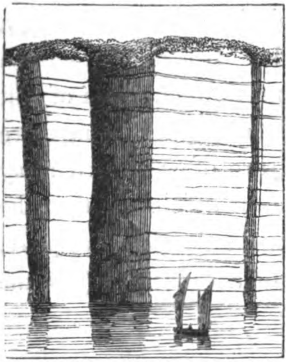
Dike in inland valley, near the Brazen Head, Madeira.

In the islands of Arran, Sky, and other parts of Scotland, where sandstone, conglomerate, and other hard rocks are traversed by dikes of trap, the converse of the above phenomenon is seen.

* I have been favoured with this drawing by Captain B. Hall.

The dike having decomposed more rapidly than the containing rock, has once more left open the original fissure, often for a distance of many yards inland from the sea-coast, as represented in the annexed view (Fig. 373.). In these instances the greenstone of the dike is usually more tough and hard than the sandstone; but chemical action, and chiefly the oxidation of the iron, has given rise to the more rapid decay.

Fig. 373.



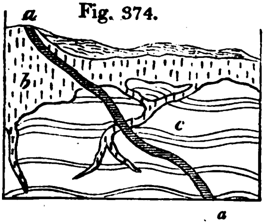
Fissures left vacant by decomposed trap. Strathaird, Sky. (MacCulloch.)

There is yet another case, by no means uncommon in Arran and other parts of Scotland, where the strata in contact with the dike, and for a certain distance from it, have been hardened, so as to resist the action of the weather more than the dike itself, or the surrounding rocks. When this happens, two parallel walls of indurated strata are seen protruding above the general level of the country, and following the course of the dike.

As fissures sometimes send off branches, or divide into two or more fissures of equal size, so also we find trap dikes bifurcating and ramifying, and sometimes they are so tortuous as to be called

veins, though this is more common in granite than in trap. The accompanying sketch (Fig. 374.) by Dr. MacCulloch represents part of a sea-cliff in Argyleshire, where an overlying mass of trap, *b*, sends out some veins which terminate downwards. Another trap vein, *a a*, cuts through both the limestone, *c*, and the trap, *b*.

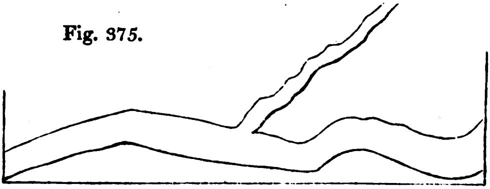
Fig. 374.



Trap veins in Airdnamurchan.

In Fig. 375. a ground plan is given of a ramifying dike of greenstone, which I observed cutting through sandstone on the beach near Kildonan Castle, in Arran. The larger branch varies from five to seven feet in width, which will afford a scale of measurement for the whole.

Fig. 375.

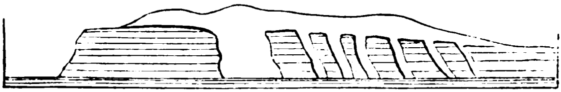


Ground plan of greenstone dike traversing sandstone. Arran.

In the Hebrides and other countries, the same masses of trap which occupy the surface of the country far and wide, concealing the subjacent stratified rocks, are seen also in the sea-cliffs, prolonged downwards in veins or dikes, which probably unite with other masses of igneous rock at

a greater depth. The largest of the dikes represented in the annexed diagram, and which are seen in part of the coast of Sky, is no less than 100 feet in width.

Fig. 376.



Trap dividing and covering sandstone near Suishnish in Sky. (MacCulloch.)

Every variety of trap rock is sometimes found in these dikes, as basalt, greenstone, felspar-porphyry, and more rarely trachyte. The amygdaloidal traps also occur, and even tuff and breccia, for the materials of these last may be washed down into open fissures at the bottom of the sea, or during eruptions on the land may be showered into them from the air.

Some dikes of trap may be followed for leagues uninterruptedly in nearly a straight direction, as in the north of England, showing that the fissures which they fill must have been of extraordinary length.

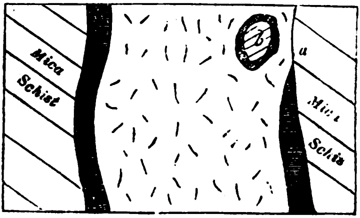
Dikes more crystalline in the centre. — In many cases trap at the edges or sides of a dike is less crystalline or more earthy than in the centre, in consequence of the melted matter having cooled more rapidly by coming in contact with the cold sides of the fissure; whereas, in the centre, the

matter of the dike being kept long in a fluid or soft state, the crystals are slowly formed. In the ancient part of Vesuvius a thin band of half-vitreous lava is found at the edge of some dikes. At the junction of greenstone dikes with lime-stone, a *sahlband*, or selvage, of serpentine is occasionally observed.

On the left shore of the fiord of Christiania, in Norway, a remarkable dike of syenitic greenstone is traced through transition strata, until at length, in the promontory of Næsodden, it enters mica-schist. Fig. 377. represents a ground plan, where

Fig. 377.

Syenitic greenstone dike of Næsodden, Christiania.

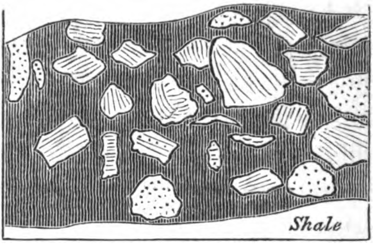


the dike appears eight paces in width. In the middle it is highly crystalline and granitiform, of a purplish colour, and containing a few crystals of mica, and strongly contrasted with the whitish mica-schist, between which and the syenitic rock there is usually on each side a distinct black band, 18 inches wide, of dark greenstone. When first seen,

these bands have the appearance of two accompanying dikes; yet they are, in fact, only the different form which the syenitic materials have assumed where near to or in contact with the mica-schist. At one point, *a*, one of the sahlbands terminates for a space; but near this there is a large detached block, *b*, having a gneiss-like structure, consisting of hornblende and felspar, which is included in the midst of the dike. Round this a smaller encircling zone is seen, of dark basalt, or fine-grained green stone, nearly corresponding to the larger ones which border the dike, but only one inch wide.*

The fact above alluded to, of a foreign fragment, such as *b* (Fig. 377.), included in the midst

Fig. 378.



Greenstone dike, with fragments of gneiss; Sorgenfri, Christiania.

of the trap, as if torn off from some subjacent rock or the walls of a fissure, is by no means uncommon. A fine illustration is seen in a dike

* This dike has been described by Professor Keilhau, of Christiania, in whose company I examined it.

of greenstone, ten feet wide, in the northern suburbs of Christiania, in Norway, of which the annexed figure is a ground plan. The dike passes through shale, known by its fossils to belong to the transition or Silurian series. In the black base of greenstone are angular and roundish pieces of gneiss, some white, others of a light flesh-colour, some without lamination, like granite, others with laminæ, which, by their various and often opposite directions, show that they have been scattered at random through the matrix. These imbedded pieces of gneiss measure from one to about eight inches in diameter.

Rocks altered by volcanic dikes. — After these remarks on the form and composition of dikes themselves, I shall describe the alterations which they sometimes produce in the rocks in contact with them. The changes are usually such as the intense heat of melted matter and the entangled gases might be expected to cause.

Plas-Newydd.—A striking example, near Plas-Newydd, in Anglesea, has been described by Professor Henslow.* The dike is 134 feet wide, and consists of a rock which is a compound of felspar and augite (dolerite of some authors). Strata of shale and argillaceous limestone, through which it cuts perpendicularly, are altered to a dis-

* Cambridge Transactions, vol. i. p. 402.

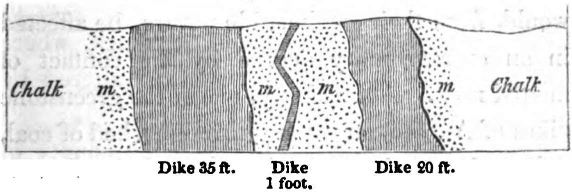
tance of thirty, or even, in some places, to thirty-five feet from the edge of the dike. The shale, as it approaches the trap, becomes gradually more compact, and is most indurated where nearest the junction. Here it loses part of its schistose structure, but the separation into parallel layers is still discernible. In several places the shale is converted into hard porcellanous jasper. In the most hardened part of the mass the fossil shells, principally *Productæ*, are nearly obliterated; yet even here their impressions may frequently be traced. The argillaceous limestone undergoes analogous mutations, losing its earthy texture as it approaches the dike, and becoming granular and crystalline. But the most extraordinary phenomenon is the appearance in the shale of numerous crystals of analcime and garnet, which are distinctly confined to those portions of the rock affected by the dike.* Garnets have been observed, under very analogous circumstances, in High Teesdale, by Professor Sedgwick, where they occur in shale and limestone, altered by basalt.†

Antrim. — In several parts of the county of Antrim, in the north of Ireland, chalk with flints is traversed by basaltic dikes. The chalk is there

* Cambridge Transactions, vol. i. p. 410.
† Ibid. vol. ii. p. 175.

converted into granular marble near the basalt, the change sometimes extending eight or ten feet from the wall of the dike, being greatest near the point of contact, and thence gradually decreasing till it becomes evanescent. "The extreme effect," says Dr. Berger, "presents a dark brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive (*metamorphic*) limestone; the next state is saccharine, then fine grained and arenaceous; a compact variety, having a porcellanous aspect and a bluish-grey colour, succeeds: this, towards the outer edge, becomes yellowish-white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour."* All traces of organic remains are effaced in that part of the limestone which is most crystalline.

Fig. 379.



Basaltic dikes in chalk in island of Rathlin, Antrim.
Ground plan, as seen on the beach. (Conybeare and Buckland.)†

* Dr. Berger, Geol. Trans., First Series, vol. iii. p. 172.
† Geol. Trans., First Series, vol. iii. p. 210. and plate 10.

The annexed drawing (Fig. 379.) represents three basaltic dikes traversing the chalk, all within the distance of ninety feet. The chalk contiguous to the two outer dikes is converted into a finely granular marble, *m m*, as are the whole of the masses between the outer dikes and the central one. The entire contrast in the composition and colour of the intrusive and invaded rocks, in these cases, renders the phenomena peculiarly clear and interesting.

Another of the dikes of the north-east of Ireland has converted a mass of red sandstone into hornstone.* By another, the slate clay of the coal measures has been indurated, and has assumed the character of flinty slate†; and in another place the slate clay of the lias has been changed into flinty slate, which still retains numerous impressions of ammonites.‡

It might have been anticipated that beds of coal would, from their combustible nature, be affected in an extraordinary degree by the contact of melted rock. Accordingly, one of the greenstone dikes of Antrim, on passing through a bed of coal, reduces it to a cinder for the space of nine feet on each side.§

* Geol. Trans., First Series, vol. iii. p. 201.

† Ibid. p. 205.

‡ Ibid. p. 213.; and Playfair, Illust. of Hutt. Theory, s. 253.

§ Geol. Trans., First Series, vol. iii. p. 206.

At Cockfield Fell, in the north of England, a similar change is observed. Specimens taken at the distance of about thirty yards from the trap are not distinguishable from ordinary pit coal; those nearer the dike are like cinders, and have all the character of coke; while those close to it are converted into a substance resembling soot.*

As examples might be multiplied without end, I shall merely select one or two others, and then conclude. The rock of Stirling Castle is a calcareous sandstone, fractured and forcibly displaced by a mass of greenstone which has evidently invaded the strata in a melted state. The sandstone has been indurated, and has assumed a texture approaching to hornstone near the junction. In Arthur's Seat and Salisbury Craig, near Edinburgh, a sandstone which comes in contact with greenstone is converted into a jaspideous rock.†

The secondary sandstones in Sky are converted into solid quartz in several places, where they come in contact with veins or masses of trap; and a bed of quartz, says Dr. MacCulloch, found near a mass of trap, among the coal strata of Fife, was in all probability a stratum of ordinary sandstone,

* Sedgwick, Camb. Trans. vol. ii. p. 37.

† Illust. of Hutt. Theory, § 253. and 261. Dr. MacCulloch, Geol. Trans., First Series, vol. ii. p. 305.

having been subsequently indurated and turned into quartzite by the action of heat.*

But although strata in the neighbourhood of dikes are thus altered in a variety of cases, shale being turned into flinty slate or jasper, limestone into crystalline marble, sandstone into quartz, coal into coke, and the fossil remains of all such strata wholly or in part obliterated, it is by no means uncommon to meet with the same rocks, even in the same districts, absolutely unchanged in the proximity of volcanic dikes.

This great inequality in the effects of the igneous rocks may often arise from an original difference in their temperature, and in that of the entangled gases, such as is ascertained to prevail in different lavas, or in the same lava near its source and at a distance from it. The power also of the invaded rocks to conduct heat may vary, according to their composition, structure, and the fractures which they may have experienced, and perhaps, also, according to the quantity of water (so capable of being heated) which they contain. It must happen in some cases that the component materials are mixed in such proportions as prepare them readily to enter into chemical union, and form new minerals; while in other cases the mass may be more homo-

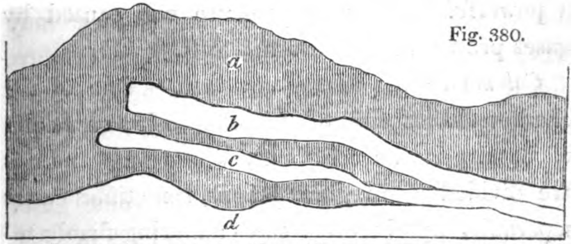
* Syst. of Geol. vol. i. p. 206.

geneous, or the proportions less adapted for such union.

We must also take into consideration, that one fissure may be simply filled with lava, which may begin to cool from the first; whereas in other cases the fissure may give passage to a current of melted matter, which may ascend for days or months, feeding streams which are overflowing the country above, or are ejected in the shape of scoriæ from some crater. If the walls of a rent, moreover, are heated by hot vapour before the lava rises, as we know may happen on the flanks of a volcano, the additional caloric supplied by the dike and its gases will act more powerfully.

Intrusion of trap between strata.—In proof of the mechanical force which the fluid trap has sometimes exerted on the rocks into which it has in-

Fig. 380.



Trap interposed between displaced beds of limestone and shale, at White Force, High Teesdale, Durham. (Sedgwick)*

truded itself, I may refer to the Whin-Sill, where a mass of basalt, from sixty to eighty feet in

* Camb. Trans. vol. ii. p. 180.

height, represented by *a*, Fig. 380., is in part wedged in between the rocks of limestone, *b*, and shale, *c*, which have been separated from the great mass of limestone and shale, *d*, with which they were united.

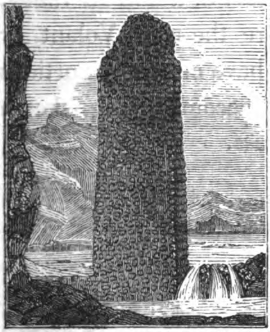
The shale in this place is indurated; and the limestone, which at a distance from the trap is blue, and contains fossil corals, is here converted into granular marble without fossils.

Masses of trap are not unfrequently met with intercalated between strata, and maintaining their parallelism to the planes of stratification throughout large areas. They must in some places have forced their way laterally between the divisions of the strata, a direction in which there would be the least resistance to an advancing fluid, if no vertical rents communicated with the surface, and a powerful hydrostatic pressure was caused by gases propelling the lava upwards.

Columnar and globular structure.—One of the characteristic forms of volcanic rocks, especially of basalt, is the columnar, where large masses are divided into regular prisms, sometimes easily separable, but in other cases adhering firmly together. The columns vary in the number of angles, from three to twelve; but they have most commonly from five to seven sides. They are often divided transversely, at nearly equal distances, like the joints in a vertebral column, as in the

Giants' Causeway, in Ireland. They vary exceedingly in respect to length and diameter. Dr. MacCulloch mentions some in Sky which are about 400 feet long; others, in Morven, not exceeding an inch. In regard to diameter, those of Ailsa measure nine feet, and those of Morven an inch or less.* They are usually straight, but sometimes curved; and examples of both these occur in the island of Staffa. In a horizontal bed or sheet of trap the columns are vertical; in a vertical dike they are horizontal. Among other examples of the last-mentioned phenomenon is the mass of basalt, called the Chimney, in St. Helena (see Fig. 381.), a pile of hexagonal prisms, 64 feet high, evidently the remainder of a narrow dike, the walls of rock which the dike originally traversed having been removed down to the level of the sea. In Fig. 382. a small portion of this dike is represented on a less reduced scale.†

Fig. 381.



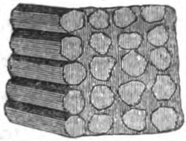
Volcanic dike composed of horizontal prisms. St. Helena.

It being assumed that columnar trap has con-

* MacCulloch, Syst. of Geol. vol. ii. p. 137.

† Seale's Geognosy of St. Helena, plate 9.

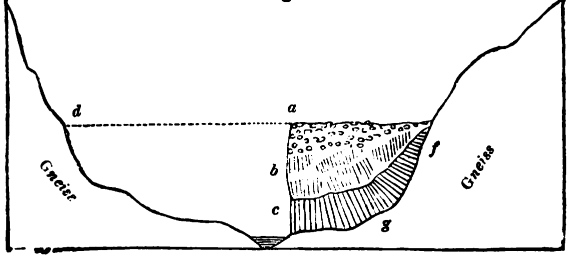
Fig. 382.



Small portion of the dike in Fig. 381.

solidated from a fluid state, the prisms are said to be always at right angles to the *cooling surfaces*. If these surfaces, therefore, instead of being either perpendicular, or horizontal, are curved, the columns ought to be inclined at every angle to the horizon; and there is a beautiful exemplification of this phenomenon in one of the valleys of the Vivarais, a mountainous district in the South of France, where, in the midst of a region of gneiss, a geologist encounters unexpectedly several volcanic cones of loose sand and scoriæ. From the crater of one of these cones, called La Coupe d'Ayzac, a stream of lava descends and occupies the bottom of a narrow valley, except at those points where the river Volant, or the torrents which join it, have cut away portions of the solid lava. The accompanying sketch

Fig. 383.



Lava of La Coupe d'Ayzac, near Antraigue, in the Province of Ardêche.

(Fig. 383.) represents the remnant of the lava at one of the points where a lateral torrent joins the

main valley of the Volant. It is clear that the lava once filled the whole valley up to the dotted line *d a*; but the river has gradually swept away all below that line, while the tributary torrent has laid open a transverse section; by which we perceive, in the first place, that the lava is composed, as usual in this country, of three parts: the uppermost, at *a*, being scoriaceous; the second, *b*, presenting irregular prisms; and the third, *c*, with regular columns, which are vertical on the banks of the Volant, where they rest on a horizontal base of gneiss, but which are inclined at an angle of 45° at *g*, and then horizontal at *f*, their position having been every where determined, according to the law before mentioned, by the concave form of the original valley.

In the annexed figure (384.) a view is given of some of the inclined and curved columns which present themselves on the sides of the valleys in the hilly region north of Vicenza, in Italy, and at the foot of the higher Alps.* Unlike those of the Vivarais, last mentioned, the basalt of this country was

Fig. 384.

Columnar basalt in the Vicentin.
(Fortis.)

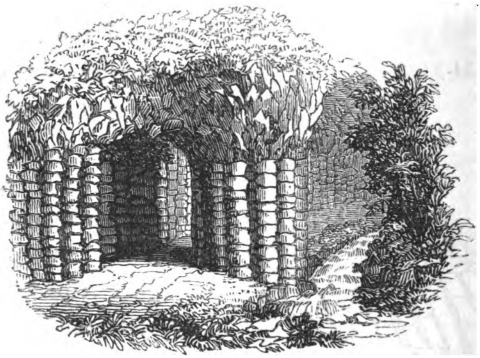
* Fortis, Mém. sur l'Hist. Nat. de l'Italie, tom. i. p. 233. plate 7.

evidently submarine, and the present valleys have since been hollowed out by denudation.

The columnar structure is by no means peculiar to the trap rocks in which hornblende or augite predominate; it is also observed in clinkstone, trachyte, and other felspathic rocks of the igneous class, although in these it is rarely exhibited in such regular polygonal forms.

It has been already stated that basaltic columns are often divided by cross joints. Sometimes each segment, instead of an angular, assumes a spheroidal form, so that a pillar is made up of a pile of balls, usually flattened, as in the Cheese-grotto at Bertrich-Baden, in the Eifel, near the Moselle. (Fig. 385.) The basalt, there, is part of

Fig. 385.



Basaltic pillars of the Käsegrotte, Bertrich-Baden, half way between Treves and Coblentz. Height of grotto, from 7 to 8 feet.

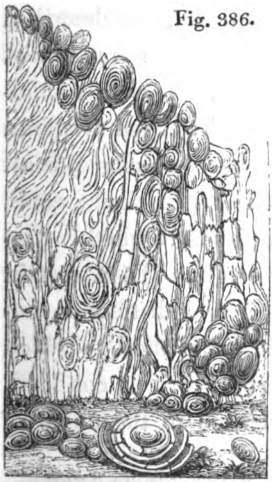
a small stream of lava, from 30 to 40 feet thick, which has proceeded from one of several volcanic

craters, still extant, on the neighbouring heights. The position of the lava bordering the river in this valley, might be represented by a section like that already given at Fig. 383. p. 228., if we merely supposed inclined strata of slate and the argillaceous sandstone called greywacké to be substituted for gneiss.

In some masses of decomposing greenstone, basalt, and other trap rocks, the globular structure is so conspicuous that the rock has the appearance of a heap of large cannon balls.

A striking example of this structure occurs in a resinous trachyte or pitchstone-porphyry in one of the Ponza islands, which rise from the Mediterranean, off the coast of Terracina and Gaieta.

Fig. 386.



Globiform pitchstone. Chiaja di Luna, Isle of Ponza. (Scrope.)

The globes vary from a few inches to three feet in diameter, and are of an ellipsoidal form (see Fig. 386.). The whole rock is in a state of decomposition, "and when the balls," says Mr. Scrope, "have been exposed a short time to the weather, they scale off at a touch into numerous concentric coats, like those of a bulbous root, inclosing a compact nucleus. The laminæ

of this nucleus have not been so much loosened by decomposition; but the application of a ruder blow will produce a still further exfoliation."*

A fissile texture is occasionally assumed by clinkstone and other trap rocks, so that they have been used for roofing houses. Sometimes the prismatic and slaty structure is found in the same mass. The causes which give rise to such arrangements are very obscure, but are supposed to be connected with changes of temperature during the cooling of the mass, as will be pointed out in the sequel. (See Chap. 34.)

Relation of trappean rocks to the products of active volcanos.

When we reflect on the changes above described in the strata near their contact with trap dikes, and consider how great is the analogy in composition and structure of the rocks called trappean and the lavas of active volcanos, it seems difficult at first to understand how so much doubt could have prevailed for half a century as to whether trap was of igneous or aqueous origin. To a certain extent, however, there was a real distinction between the trappean formations and those to which the term volcanic was almost exclusively confined. The trappean rocks first studied in the north of

* Scrope, Geol. Trans. vol. ii. p. 205. Second Series.

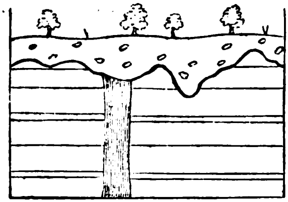
Germany, and in Norway, France, Scotland, and other countries, were either such as had been formed entirely under deep water, or had been injected into fissures and intruded between strata, and which had never flowed out in the air, or over the bottom of a shallow sea. When these products, therefore, of submarine or subterranean igneous action were contrasted with loose cones of scoriæ, tuff, and lava, or with narrow streams of lava in great part scoriaceous and porous, such as were observed to have proceeded from Vesuvius and Etna, the resemblance seemed remote and equivocal. It was, in truth, like comparing the roots of a tree with its leaves and branches, which, although they belong to the same plant, differ in form, texture, colour, mode of growth, and position. The external cone, with its loose ashes and porous lava, may be likened to the light foliage and branches, and the rocks concealed far below, to the roots. But it is not enough to say of the volcano,

> "quantum vertice in auras
> Ætherias, tantum radice in Tartara tendit,"

for its roots do literally reach downwards to Tartarus, or to the regions of subterranean fire; and what is concealed far below, is probably always more important in volume and extent than what is visible above ground.

We have already stated how frequently dense masses of strata have been removed by denudation from wide areas (see Chap. VI.); and this fact prepares us to expect a similar destruction of whatever may once have formed the uppermost part of ancient submarine or subaërial volcanos, more especially as those superficial parts are always of the lightest and most perishable materials. The abrupt manner in which dikes of trap usually terminate at the surface (see Fig. 387.), and the water-worn pebbles of trap in the alluvium which covers the dike, prove incontestably that whatever was uppermost in these formations has been swept away. It is easy, therefore, to conceive that what is gone in regions of trap may have corresponded to what is now visible in active volcanos.

Fig. 387.



Strata intersected by a trap dike, and covered with alluvium.

It will be seen in the following chapters, that in the earth's crust there are volcanic tuffs of all ages, containing marine shells, which bear witness to eruptions at many successive geological periods. These tuffs, and the associated trappean rocks, must not be compared to lava and scoriæ which had cooled in the open air. Their counterparts must be sought in the products of modern submarine volcanic erup-

tions. If it be objected that we have no opportunity of studying these last, it may be answered, that subterranean movements have caused, almost everywhere in regions of active volcanos, great changes in the relative level of land and sea, in times comparatively modern, so as to expose to view the effects of volcanic operations at the bottom of the sea.

Thus, for example, the recent examination of the igneous rocks of Sicily, especially those of the Val di Noto, has proved that all the more ordinary varieties of European trap have been there produced under the waters of the sea, at a modern period; that is to say, since the Mediterranean has been inhabited by a great proportion of the existing species of testacea.

These igneous rocks of the Val di Noto, and the more ancient trappean rocks of Scotland and other countries, differ from subaerial volcanic formations in being more compact and heavy, and in forming sometimes extensive sheets of matter intercalated between marine strata, and sometimes stratified conglomerates, of which the rounded pebbles are all trap. They differ also in the absence of regular cones and craters, and in the want of conformity of the lava to the lowest levels of existing valleys.

It is highly probable, however, that insular cones did exist in some parts of the Val di Noto:

and that they were removed by the waves, in the same manner as the cone of Graham Island, in the Mediterranean, was swept away in 1831, and that of Nyöe, off Iceland, in 1783. All that would remain in such cases, after the bed of the sea has been upheaved and laid dry, would be dikes and shapeless masses of igneous rock, cutting through sheets of lava which may have spread over the level bottom of the sea, and strata of tuff, formed of materials first scattered far and wide by the winds and waves, and then deposited. Trap conglomerates also, to which the action of the waves must give rise during the denudation of such volcanic islands, will emerge from the deep whenever the bottom of the sea becomes land.*

The proportion of volcanic matter which is originally submarine must always be very great, as those volcanic vents which are not entirely beneath the sea, are almost all of them in islands, or, if on continents, near the shore. This may explain why extended sheets of trap so often occur, instead of narrow threads, like lava streams. For, a multitude of causes tend, near the land, to reduce the bottom of the sea to a nearly uniform level,—the sediment of rivers,—materials transported by the waves and currents of the sea from wasting cliffs,

* See Princ. of Geol., *Index*, "Graham Island," "Nyöe," "Conglomerates, volcanic," &c.

—showers of sand and scoriæ ejected by volcanos, and scattered by the wind and waves. When, therefore, lava is poured out on such a surface, it will spread far and wide in every direction in a liquid sheet, which may afterwards, when raised up, form the tabular capping of the land.

As to the absence of porosity in the trappean formations, the appearances are in a great degree deceptive, for all amygdaloids are, as already explained, porous rocks, into the cells of which mineral matter, such as silex, carbonate of lime, and other ingredients, have been subsequently introduced. (See p. 200.)

In the Little Cumbray, one of the Western Islands, near Arran, the amygdaloid sometimes contains elongated cavities filled with brown spar; and when the nodules have been washed out, the interior of the cavities is glazed with the vitreous varnish so characteristic of the pores of slaggy lavas. Even in some parts of this rock which are excluded from air and water, the cells are empty, and seem to have always remained in this state, and are therefore undistinguishable from some modern lavas.*

Dr. MacCulloch, after examining with great attention these and the other igneous rocks of Scotland, observes, "that it is a mere dispute about

* MacCulloch, West. Isl., vol. ii. p. 487.

terms, to refuse to the ancient eruptions of trap the name of submarine volcanos; for they are such in every essential point, although they no longer eject fire and smoke."* The same author also considers it not improbable that some of the volcanic rocks of the same country may have been poured out in the open air.†

Although the principal component minerals of subaerial lavas are the same as those of intrusive trap, and both the columnar and globular structure are common to both, there are, nevertheless, some volcanic rocks which never occur as lava, such as greenstone, clinkstone, the more crystalline porphyries, and all those traps in which quartz and mica frequently appear as constituent parts. In short, the intrusive trap rocks, forming the intermediate step between lava and the plutonic rocks, depart in their characters from lava in proportion as they approximate to granite.

These views respecting the relations of the volcanic and trap rocks will be better understood when the reader has studied, in the 32nd chapter, what is said of the plutonic formations.

* Syst. of Geol., vol. ii. p. 114. † Ibid.

CHAPTER XXIX.

ON THE DIFFERENT AGES OF THE VOLCANIC ROCKS.

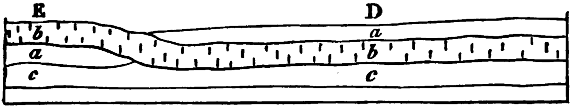
Tests of relative age of volcanic rocks — Test by superposition and intrusion — Dike of Quarrington Hill, Durham — Test by alteration of rocks in contact —Test by organic remains — Test of age by mineral character — Test by included fragments — Volcanic rocks of the Post-Pliocene period — Basalt of Bay of Trezza in Sicily—Post-Pliocene volcanic rocks near Naples — Dikes of Somma — Igneous formations of the Newer Pliocene period—Val di Noto in Sicily.

Having referred the sedimentary strata to a long succession of geological periods, we have next to consider how far the volcanic formations can be classed in a similar chronological order. The tests of relative age in this class of rocks are four: — 1st, superposition and intrusion, with or without alteration of the rocks in contact; 2d, organic remains; 3d, mineral character; 4th, included fragments of older rocks.

Test by superposition, &c. — If a volcanic rock rest upon an aqueous deposit, the former must be the newest of the two, but the like rule does not hold good where the aqueous formation rests upon the volcanic, for we have already seen (p. 225.) that melted matter, rising from below, may penetrate a sedimentary mass without reaching the

surface, or may be forced in conformably between two strata, as *b* at D in the annexed figure (Fig. 388.) after which it may cool down and consolidate. Superposition, therefore, is not of the

Fig. 388.

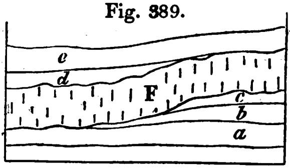


same value as a test of age in the unstratified volcanic rocks as in fossiliferous formations. We can only rely implicitly on this test where the volcanic rocks are contemporaneous, not where they are intrusive. Now they are said to be contemporaneous if produced by volcanic action, which was going on simultaneously with the deposition of the strata with which they are associated. Thus in the section at D (Fig. 388.), we may perhaps ascertain that the trap *b* flowed over the fossiliferous bed *c*, and that, after its consolidation, *a* was deposited upon it, *a* and *c* both belonging to the same geological period. But if the stratum *a* be altered by *b* at the point of contact, we must then conclude the trap to have been intrusive, or if, in pursuing *b* for some distance, we find at length that it cuts through the stratum *a*, and then overlies it.

We may, however, be easily deceived in supposing a volcanic rock to be intrusive, when in reality it is contemporaneous, for a sheet of lava,

as it spreads over the bottom of the sea, cannot rest every where upon the same stratum, either because these have been denuded, or because, if newly thrown down, they thin out in certain places, thus allowing the lava to cross their edges. Besides, the heavy igneous fluid will often, as it moves along, cut a channel into beds of soft mud and sand. Suppose the submarine lava F to have come in contact in this manner with the strata *a*, *b*, *c*, and that, after its consolidation, the strata *d*, *e*, are thrown down in a nearly horizontal position, yet so as to lie unconformably to F, the appearance of subsequent intrusion will here be complete, although the trap is in fact contemporaneous. We must, unless we find the strata *d* or *e* to have been altered at their junction, as if by heat, not therefore hastily infer that the rock F is intrusive.

Fig. 389.

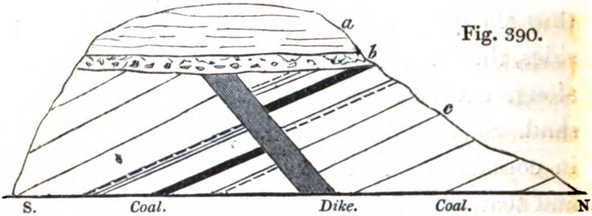


When trap dikes were described in the preceding chapter, they were shown to be more modern than all the strata which they traverse. A basaltic dike at Quarrington Hill, near Durham, passes through Coal-measures, the strata of which are inclined, and shifted so that those on the north side of the dike are 24 feet above the level of the corresponding beds on the south

side (see section, fig. 390.). But the horizontal beds of overlying New Red Sandstone and Mag-

Magnesian Limestone.

Fig. 390.



Section at Quarrington Hill, east of Durham. (Sedgwick.*)

a. Magnesian Limestone. *b.* Lower New Red Sandstone. *c.* Coal strata.

nesian Limestone are not cut through by the dike. Now here the Coal-measures were not only deposited, but had subsequently been disturbed, fissured, and shifted, before the fluid trap now forming the dike was introduced into a rent. It is also clear that some of the upper edges of the coal strata, together with the upper part of the dike, had been subsequently removed by denudation before the lower New Red Sandstone and Magnesian

* This illustration, for which I am indebted to Professor Sedgwick, is substituted for one given in the first edition, p. 470., which had been taken from the Geol. Trans., vol. iv., where a dike is incorrectly represented at Cullercoats, Northumberland. At that spot, which I have since visited, there is no trap dike, but only a great fault. See Sedgwick, Cambridge Trans.

Limestone were superimposed. Even in this case, however, although the date of the volcanic eruption is brought within narrow limits, it cannot be defined with precision; it may have happened either at the close of the Carboniferous period, or early in that of the lower New Red Sandstone, or between these two periods, when the state of the animate creation and the physical geography of Europe were gradually changing from the type of the Carboniferous era to that of the lower New Red formation.

The test of age by superposition is strictly applicable to all stratified volcanic tuffs, according to the rules as already explained in the case of other sedimentary deposits. (See Vol. I. p. 197.)

Test of age by organic remains.—We have seen how, in the vicinity of active volcanos, scoriæ, pumice, fine sand, and fragments of rock are thrown up into the air, and then showered down upon the land, or into neighbouring lakes or seas. In the tuffs so formed shells, corals, or any other durable organic bodies which may happen to be strewed over the bottom of a lake or sea will be imbedded, and thus continue as permanent memorials of the geological period when the volcanic eruption occurred. Tufaceous strata thus formed in the neighbourhood of Vesuvius, Etna, Stromboli, and other volcanos now active in islands

or near the sea, may give information of the relative age of these tuffs at some remote future period when the fires of these mountains are extinguished. By such evidence we can distinctly establish the coincidence in age of volcanic rocks, and the different primary, secondary, and tertiary fossiliferous strata already considered.

The tuffs now alluded to are not exclusively marine, but include, in some places, freshwater shells; in others, the bones of terrestrial quadrupeds. The diversity of organic remains in formations of this nature is perfectly intelligible, if we reflect on the wide dispersion of ejected matter during late eruptions, such as that of the volcano of Coseguina, in the province of Nicaragua, January 19. 1835. Hot cinders and fine scoriæ were then cast up to a vast height, and covered the ground as they fell to the depth of more than ten feet, and for a distance of eight leagues from the crater in a southerly direction. Birds, cattle, and wild animals were scorched to death in great numbers, and buried in these ashes. Some volcanic dust fell at Chiapa, upwards of 1200 miles to windward of the volcano, a striking proof of a counter current in the upper region of the atmosphere; and some on Jamaica, about 700 miles distant to the north-east. In the sea, also, at the distance of 1100 miles from the point of eruption, Captain Eden of the

Conway sailed 40 miles through floating pumice, among which were some pieces of considerable size.*

Test of age by mineral composition. — As sediment of homogeneous composition, when discharged from the mouth of a large river, is often deposited simultaneously over a wide space, so a particular kind of lava flowing from a crater during one eruption, may spread over an extensive area; as in Iceland in 1783, when the melted matter, pouring from Skaptar Jokul, flowed in streams in opposite directions, and caused a continuous mass, the extreme points of which were 90 miles distant from each other. This enormous current of lava varied in thickness from 100 feet to 600 feet, and in breadth from that of a narrow river gorge to 15 miles.† Now, if such a mass should afterwards be divided into separate fragments by denudation, we might still perhaps identify the detached portions by their similarity in mineral composition. Nevertheless, this test will not always avail the geologist; for, although there is usually a prevailing character in lava emitted during the same eruption, and even in the successive currents flowing from the same volcano, still, in many cases, the different parts even of one lava-stream, or, as before stated,

* Caldcleugh, Phil. Trans. 1836, p. 27., and Official Documents of Nicaragua.

† See Principles, *Index*, "Skaptar Jokul."

of one continuous mass of trap, vary so much in mineral composition and texture as to render these characters of minor importance when compared to their value in the chronology of the fossiliferous rocks.

It will, however, be seen in the description which follows, of the European trap rocks of different ages, that they had often a peculiar lithological character, resembling the differences before remarked as existing between the modern lavas of Vesuvius, Etna, and Chili. (See p. 202.)

It has been remarked that in Auvergne, the Eifel, and other countries where trachyte and basalt are both present, the trachytic rocks are for the most part older than the basaltic. These rocks do, indeed, sometimes alternate partially, as in the volcano of Mont Dor, in Auvergne; but the great mass of trachyte occupies in general an inferior position, and is cut through and overflowed by basalt. It can by no means be inferred that trachyte predominated greatly at one period of the earth's history and basalt at another, for we know that trachytic lavas have been formed at many successive periods, and are still emitted from many active craters; but it seems that in each region, where a long series of eruptions have occurred, the more felspathic lavas have been first emitted, and the escape of the more augitic kinds has followed. The hypothesis suggested by

Mr. Scrope may, perhaps, afford a solution of this problem. The minerals, he observes, which abound in basalt are of greater specific gravity than those composing the felspathic lavas; thus, for example, hornblende, augite, and olivine are each more than three times the weight of water; whereas common felspar, albite, and Labrador felspar, have each scarcely more than 2½ times the specific gravity of water; and the difference is increased in consequence of there being much more iron in a metallic state in basalt and greenstone than in trachyte and other felspathic lavas and traps. If, therefore, a large quantity of rock be melted up in the bowels of the earth by volcanic heat, the denser ingredients of the boiling fluid will sink to the bottom, and the lighter remaining above will be first propelled upwards to the surface by the expansive power of gases. Those materials, therefore, which occupied the lowest place in the subterranean reservoir will always be emitted last, and take the uppermost place on the exterior of the earth's crust.

Test by included fragments. — We may sometimes discover the relative age of two trap rocks, or of an aqueous deposit and the trap on which it rests, by finding fragments of one included in the other, in cases such as those before alluded to, where the evidence of superposition alone would be insufficient. It is also not uncommon to find

conglomerates almost exclusively composed of rolled pebbles of trap, associated with stratified rocks in the neighbourhood of masses of intrusive trap. If the pebbles agree generally in mineral character with the latter, we are then enabled to determine the age of the intrusive rock by knowing that of the fossiliferous strata associated with the conglomerate. The origin of such conglomerates is explained by observing the shingle beaches composed of trap pebbles in modern volcanic islands, or at the base of Etna.

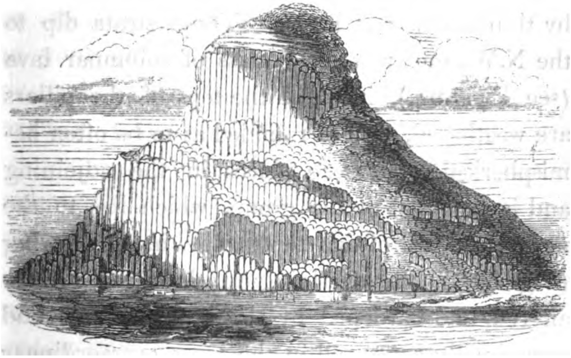
Post-Pliocene Period (*including the Recent*). — I shall now select examples of contemporaneous volcanic rocks of successive geological periods, to show that igneous causes have been in activity in all past ages of the world, and that they have been ever shifting the places where they have broken out at the earth's surface.

One portion of the lavas, tuffs, and trap-dikes of Etna, Vesuvius, and the island of Ischia, has been produced within the historical era; another, and a far more considerable part, originated at times immediately antecedent, when the waters of the Mediterranean were already inhabited by the existing species of testacea. By consulting the map (plate 2.) the reader will see that the southern and eastern flanks of Etna are skirted by a fringe of sedimentary deposits, as at Aderno, Trezza, and other places. These are designated

in the map as Newer Pliocene, alternating with volcanic. The strata are marine; but fossils have scarcely yet been collected in sufficient number to enable us to decide whether they were formed during the Post-Pliocene, or at the close of the Newer Pliocene period. Of 65 species of shells which I procured near Trezza, it was scarcely possible to distinguish any from species now living in the neighbouring sea.

The Cyclopian Islands, called by the Sicilians Dei Faraglioni, in the sea cliffs of which these

Fig. 391.



*View of the Isle of Cyclops in the Bay of Trezza.**

beds and the associated volcanic rocks are laid open to view, are situated in the Bay of Trezza,

* This view of the Isle of Cyclops is from an original drawing by my friend Captain Basil Hall, R.N.

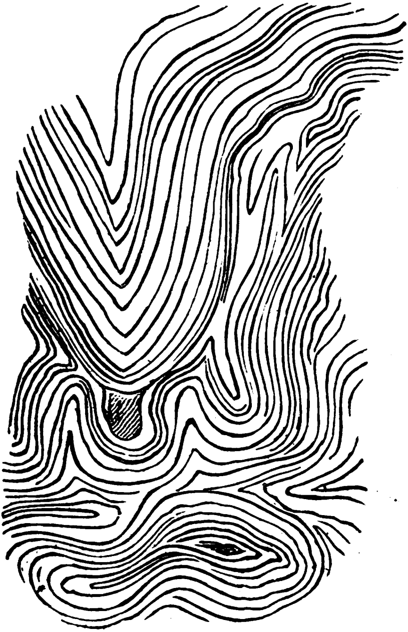
and may be regarded as the extremity of a promontory severed from the main land. Here numerous proofs are seen of submarine eruptions, by which the argillaceous and sandy strata were invaded and cut through, and tufaceous breccias formed. Inclosed in these breccias are many angular and hardened fragments of laminated clay in different states of alteration by heat, and intermixed with volcanic sands.

The loftiest of the Cyclopian islets, or rather rocks, is about two hundred feet in height, the summit being formed of a mass of stratified clay, the laminæ of which are occasionally subdivided by thin arenaceous layers. These strata dip to the N.W., and rest on a mass of columnar lava (see Fig. 391.), in which the tops of the pillars are weathered, and so rounded as to be often hemispherical. In some places in the adjoining and largest islet of the group, which lies to the north-eastward of that represented in the drawing (Fig. 391.), the overlying clay has been greatly altered, and hardened by the igneous rock, and occasionally contorted in the most extraordinary manner; yet the lamination has not been obliterated, but, on the contrary, rendered much more conspicuous, by the indurating process.

The annexed wood cut (Fig. 392.) is a careful representation of a portion of the altered rock, a few feet square, where the alternating thin laminæ

of sand and clay have put on the appearance which we often observe in some of the most contorted of the metamorphic schists.

Fig. 392.



Contortions in the strata of the largest of the Cyclopian Islands.

A great fissure, running from east to west, nearly divides this larger island into two parts, and lays open its internal structure. In the section thus exhibited a dike of lava is seen, first cutting through an older mass of lava, and then penetrating the superincumbent tertiary strata.

In one place the lava ramifies and terminates in thin veins, from a few feet to a few inches in thickness (see Fig. 393.).

Fig. 393.

Newer Pliocene strata invaded by lava, Isle of Cyclops (horizontal section).

a. Lava. *b.* Laminated clay and sand. *c.* The same altered.

The arenaceous laminæ are much hardened at the point of contact, and the clays are converted into siliceous schist. In this island the altered rocks assume a honeycombed structure on their weathered surface, singularly contrasted with the smooth and even outline which the same beds present in their usual soft and yielding state.

The pores of the lava are sometimes coated, or entirely filled, with carbonate of lime, and with a zeolite resembling analcime, which has been called

cyclopite. The latter mineral has also been found in small fissures traversing the altered marl, showing that the same cause which introduced the minerals into the cavities of the lava, whether we suppose sublimation or aqueous infiltration, conveyed it also into the open rents of the contiguous sedimentary strata.

Post-Pliocene formations near Naples. — I have traced in the "Principles of Geology" the history of the changes which the volcanic region of Campania is known to have undergone during the last 2000 years. The aggregate effect of igneous operations during that period is far from insignificant, comprising as it does the formation of the modern cone of Vesuvius since the year 79, and the production of several minor cones in Ischia, together with that of Monte Nuovo in the year 1538. Lava currents have also flowed upon the land and along the bottom of the sea—volcanic sand, pumice, and scoriæ have been showered down so abundantly that whole cities were buried—tracts of the sea have been filled up or converted into shoals, and tufaceous sediment has been transported by rivers and land floods to the sea. There are also proofs during the same recent period of a permanent alteration of the relative levels of the land and sea in several places, and of the same tract having, near Puzzuoli, been alternately upheaved and depressed to the amount of more than twenty

feet. In connection with these convulsions, there are found, on the shores of the Bay of Baiæ, recent tufaceous strata filled with articles fabricated by the hands of man, and mingled with marine shells.

It was before stated in this work, that when we examine this same region it is found to consist largely of tufaceous strata, of a date anterior to human history or tradition, which are of such thickness as to constitute hills from 500 to more than 2000 feet in height. These strata, containing recent marine shells, alternate with distinct currents and sheets of lava which were of contemporaneous origin; and we find that in Vesuvius itself, the ancient cone called Somma is of far greater volume than the modern cone, and is intersected by a far greater number of dikes. In contrasting this ancient part of the mountain with that of modern date, one principal point of difference is observed; namely, the greater frequency in the older cone of fragments of altered sedimentary rocks ejected during eruptions. We may easily conceive that the first explosions would act with the greatest violence, rending and shattering whatever solid masses obstructed the escape of lava and the accompanying gases, so that great heaps of ejected pieces of rock would naturally occur in the tufaceous breccias formed by the earliest eruptions. But when a passage had once

been opened and an habitual vent established, the materials thrown out would consist of liquid lava, which would take the form of sand and scoriæ, or of angular fragments of such solid lavas as may have choked up the vent.

Among the fragments which abound in the tufaceous breccias of Somma, none are more common than a saccharoid dolomite, supposed to have been derived from an ordinary limestone altered by heat and volcanic vapours.

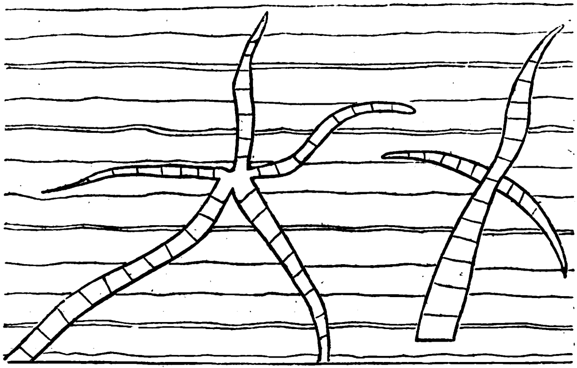
Carbonate of lime enters into the composition of so many of the simple minerals found in Somma, that M. Mitscherlich, with much probability, ascribes their great variety to the action of the volcanic heat on subjacent masses of limestone.

Dikes of Somma. — The dikes seen in the great escarpment which Somma presents towards the modern cone of Vesuvius are very numerous. They are for the most part vertical, and traverse at right angles the beds of lava, scoriæ, volcanic breccia, and sand, of which the ancient cone is composed. They project in relief several inches, or sometimes feet, from the face of the cliff, being extremely compact, and less destructible than the intersected tuffs and porous lavas. In vertical extent they vary from a few yards to 500 feet, and in breadth from one to twelve feet. Many of them cut all the inclined beds in the escarpment of Somma from top to bottom, others stop short

before they ascend above half way, and a few terminate at both ends, either in a point or abruptly. In mineral composition they scarcely differ from the lavas of Somma, the rock consisting of a base of leucite and augite, through which large crystals of augite and some of leucite are scattered.* Examples are not rare of one dike cutting through another, and in one instance a shift or fault is seen at the point of intersection.

In some cases, however, the rents seem to have been filled laterally, when the walls of the crater had been broken by star-shaped cracks, as seen in the accompanying wood cut (Fig. 394.).

Fig. 394.



Dikes or veins at the Punto del Nasone on Somma. (Necker †)

* Consult the valuable memoir of M. L. A. Necker, Mém. de la Soc. de Phys. et d'Hist. Nat. de Génève, tom. ii. part i. Nov. 1822.

† From a drawing of M. Necker, in Mém. above cited.

But the shape of these rents is an exception to the general rule; for nothing is more remarkable than the usual parallelism of the opposite sides of the dikes, which correspond almost as regularly as the two opposite faces of a wall of masonry. This character appears at first the more inexplicable, when we consider how jagged and uneven are the rents caused by earthquakes in masses of heterogeneous composition like those composing the cone of Somma. In explanation of this phenomenon, M. Necker refers us to Sir W. Hamilton's account of an eruption of Vesuvius in the year 1779, who records the following facts: — "The lavas, when they either boiled over the crater, or broke out from the conical parts of the volcano, constantly formed channels as regular as if they had been cut by art down the steep part of the mountain; and, whilst in a state of perfect fusion, continued their course in those channels, which were sometimes full to the brim, and at other times more or less so, according to the quantity of matter in motion.

"These channels, upon examination after an eruption, I have found to be in general from two to five or six feet wide, and seven or eight feet deep. They were often hid from the sight by a quantity of scoriæ that had formed a crust over them; and the lava having been conveyed in a covered way for some yards, came out fresh again into an open channel. After an eruption I have

walked in some of those subterraneous or covered galleries, which were exceedingly curious, the sides, top, and bottom *being worn perfectly smooth and even* in most parts, by the violence of the currents of the red-hot lavas which they had conveyed for many weeks successively."*

Now, the walls of a vertical fissure through which lava has ascended in its way to a volcanic vent, must have been exposed to the same erosion as the sides of the channels before adverted to. The prolonged and uniform friction of the heavy fluid, as it is forced and made to flow upwards, cannot fail to wear and smooth down the surfaces on which it rubs, and the intense heat must melt all such masses as project and obstruct the passage of the incandescent fluid.

The texture of the Vesuvian dikes is different at the edges and in the middle. Towards the centre, observes M. Necker, the rock is larger grained, the component elements being in a far more crystalline state; while at the edge the lava is sometimes vitreous, and always finer grained. A thin parting band, approaching in its character to pitchstone, occasionally intervenes on the contact of the vertical dike and intersected beds. M. Necker mentions one of these at the place called Primo Monte, in the Atrio del Cavallo; and when

* Phil. Trans., vol. lxx., 1780.

on Somma, in 1828, I saw three or four others in different parts of the great escarpment. These phenomena are in perfect harmony with the results of the experiments of Sir James Hall and Mr. Gregory Watt, which have shown that a glassy texture is the effect of sudden cooling, and that, on the contrary, a crystalline grain is produced where fused minerals are allowed to consolidate slowly and tranquilly under high pressure.

It is evident that the central portion of the lava in a fissure would, during consolidation, part with its heat more slowly than the sides, although the contrast of circumstances would not be so great as when we compare the lava at the bottom and at the surface of a current flowing in the open air. In this case the uppermost part, where it has been in contact with the atmosphere, and where refrigeration has been most rapid, is always found to consist of scoriform, vitreous, and porous lava; while at a greater depth the mass assumes a more lithoidal structure, and then becomes more and more stony as we descend, until at length we are able to recognize with a magnifying glass the simple minerals of which the rock is composed. On penetrating still deeper, we can detect the constituent parts by the naked eye, and in the Vesuvian currents distinct crystals of augite and leucite become apparent.

The same phenomenon, observes M. Necker,

may readily be exhibited on a smaller scale, if we detach a piece of liquid lava from a moving current. The fragment cools instantly, and we find the surface covered with a vitreous coat, while the interior, although extremely fine-grained, has a more stony appearance.

It must, however, be observed, that although the lateral portions of the dikes are finer grained than the central, yet the vitreous parting layer before alluded to is rare in Vesuvius. This may, perhaps, be accounted for, as the above-mentioned author suggests, by the great heat which the walls of a fissure may acquire before the fluid mass begins to consolidate, in which case the lava, even at the sides, would cool very slowly. Some fissures, also, may be filled from above; and in this case the refrigeration at the sides would be more rapid than when the melted matter flowed upwards from the volcanic foci, in an intensely heated state. Mr. Darwin informs me that in St. Helena almost every dike has a vitreous selvage.

The rock composing the dikes both in the modern and ancient part of Vesuvius is far more compact than that of ordinary lava, for the pressure of a column of melted matter in a fissure greatly exceeds that in an ordinary stream of lava; and pressure checks the expansion of those gases which give rise to vesicles in lava.

There is a tendency in almost all the Vesuvian

dikes to divide into horizontal prisms, a phenomenon in accordance with the formation of vertical columns in horizontal beds of lava; for in both cases the divisions which give rise to the prismatic structure are at right angles to the cooling surfaces.

Newer Pliocene period — Val di Noto. — I have already alluded on more than one occasion (see p. 235. and Vol. I. p. 293.) to the igneous rocks which are associated with a great marine formation of limestone, sand, and marl, in the southern part of Sicily, as at Vizzini and other places. (See Map, plate 2.) In this formation, which was shown to belong to the Newer Pliocene period, large beds of oysters and corals repose upon lava, and are unaltered at the point of contact. In other places we find dikes of igneous rock intersecting the fossiliferous beds, and converting the clays into siliceous schist, the laminæ being contorted and shivered into innumerable fragments at the junction, as near the town of Vizzini.

The volcanic formations of the Val di Noto usually consist of the most ordinary variety of basalt, with or without olivine. The rock is sometimes compact, often very vesicular. The vesicles are occasionally empty, both in dikes and currents, and are in some localities filled with calcareous spar, arragonite, and zeolites. The structure is, in some places, spheroidal; in others, though

rarely, columnar. I found dikes of amygdaloid, wacké, and prismatic basalt, intersecting the limestone at the bottom of the hollow called Gozzo degli Martiri, below Melilli.

Dikes. — Dikes of vesicular and amygdaloidal lava are also seen traversing marine tuff or peperino, west of Palagonia, some of the pores of the

Fig. 395.

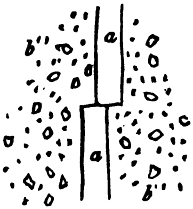
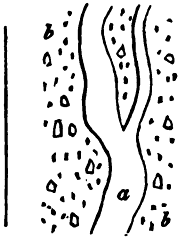


Fig. 396.



Ground plan of dikes near Palagonia.

a Lava.

b. Peperino, consisting of volcanic sand, mixed with fragments of lava and limestone.

lava being empty, while others are filled with carbonate of lime. In such cases, we may suppose the peperino to have resulted from showers of volcanic sand and scoriæ, together with fragments of limestone thrown out by a submarine explosion, similar to that which gave rise to Graham Island in 1831. When the mass was, to a certain degree, consolidated, it may have been rent open, so that the lava ascended through fissures, the walls of which were perfectly even and

parallel. After the melted matter that filled the rent in Fig. 395. had cooled down, it must have been fractured and shifted horizontally by a lateral movement.

In the second figure, No. 396., the lava has more the appearance of a vein which forced its way through the peperino. It is highly probable that similar appearances would be seen, if we could examine the floor of the sea in that part of the Mediterranean where the waves have recently washed away the new volcanic island; for when a superincumbent mass of ejected fragments has been removed by denudation, we may expect to see sections of dikes traversing tuff, or, in other words, sections of the channels of communication by which the subterranean lavas reached the surface.

CHAPTER XXX.

ON THE DIFFERENT AGES OF THE VOLCANIC ROCKS—*continued.*

Volcanic rocks of the Older Pliocene period — Tuscany — Rome — Volcanic region of Olot in Catalonia — Cones and lava-currents — Ravines and ancient gravel-beds — Jets of air called Bufadors — Age of the Catalonian volcanos — Miocene period — Brown coal of the Eifel and contemporaneous trachytic breccias — Age of the Brown coal — Peculiar characters of the volcanos of the upper and lower Eifel — Lake craters — Trass — Hungarian volcanos.

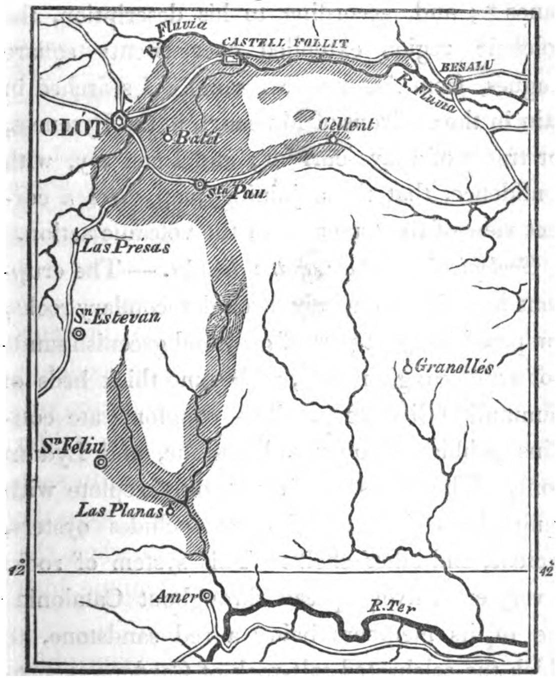
Older Pliocene period — Tuscany. — In Tuscany, as at Radicofani, Viterbo, and Aquapendente, and in the Campagna di Roma, submarine volcanic tuffs are interstratified with the Older Pliocene strata of the Subapennine hills, in such a manner as to leave no doubt that they were the products of eruptions which occurred when the shelly marls and sands of the Subapennine hills were in the course of deposition.

Catalonia. — Geologists are far from being able, as yet, to assign to each of the volcanic groups scattered over Europe a precise chronological place in the tertiary series; but I shall describe

here, as probably referable to the Older Pliocene period, a district of extinct volcanos near Olot, in the north of Spain, which is little known, and which I visited in the summer of 1830.

The whole extent of country occupied by volcanic products in Catalonia is not more than

Fig. 397.



Volcanic district of Catalonia.

fifteen geographical miles from north to south, and about six from east to west. The vents of

eruption range entirely within a narrow band running north and south; and the branches, which are represented as extending eastward in the map, are formed simply of two lava-streams — those of Castell Follit and Cellent.

Dr. Maclure, the American geologist, was the first who made known the existence of these volcanos *; and, according to his description, the volcanic region extended over twenty square leagues, from Amer to Massanet. I searched in vain in the environs of Massanet, in the Pyrenees, for traces of a lava-current; and I can say, with confidence, that the adjoining map gives a correct view of the true area of the volcanic action.

Geological structure of the district. — The eruptions have burst entirely through secondary rocks, composed in great part of grey and greenish sandstone and conglomerate, with some thick beds of nummulitic limestone. The conglomerate contains pebbles of quartz, limestone, and Lydian stone. The limestone is not only replete with nummulites, but occasionally includes oysters, pectens, and other shells. This system of rocks is very extensively spread throughout Catalonia; one of its members being a red sandstone, to which the celebrated salt-rock of Cardona is sub-

* Maclure, Journ. de Phys., vol. lxvi. p. 219., 1808; cited by Daubeny, Description of Volcanos, p. 24.

ordinate. The whole is now generally considered as belonging to the age of our green-sand and chalk.

Near Amer, in the Valley of the Ter, on the southern borders of the region delineated in the map, primary rocks are seen, consisting of gneiss, mica-schist, and clay-slate. They run in a line nearly parallel to the Pyrenees, and throw off the secondary strata from their flanks, causing them to dip to the north and north-west. This dip, which is towards the Pyrenees, is connected with a distinct axis of elevation, and prevails through the whole area described in the map, the inclination of the beds being sometimes at an angle of between 40 and 50 degrees.

It is evident that the physical geography of the country has undergone no material change since the commencement of the era of the volcanic eruptions, except such as has resulted from the introduction of new hills of scoriæ, and currents of lava upon the surface. If the lavas could be remelted and poured out again from their respective craters, they would descend the same valleys in which they are now seen, and re-occupy the spaces which they at present fill. The only difference in the external configuration of the fresh lavas would consist in this, that they would nowhere be intersected by ravines, or exhibit marks of erosion by running water.

Volcanic cones and lavas. — There are about fourteen distinct cones with craters in this part of Spain, besides several points whence lavas may have issued; all of them arranged along a narrow line running north and south, as will be seen in the map. The greatest number of perfect cones are in the immediate neighbourhood of Olot, some of which are represented in the annexed plate (Pl. VII.); and the level plain on which that town stands has clearly been produced by the flowing down of many lava-streams from those hills into the bottom of a valley, probably once of considerable depth, like those of the surrounding country.

In this plate an attempt is made to represent by colours the different geological formations of which the country is composed.* The blue line of mountains in the distance are the Pyrenees, which are to the north of the spectator, and consist of hypogene and ancient fossiliferous rocks. In front of these are the secondary formations described in this chapter, coloured grey. Different shades of this colour are introduced, to express various distances. The flank of the hill, in the foreground, called Costa de Pujou, is composed partly of secondary rocks, and partly

* This view is taken from a sketch which I made on the spot in 1830.

of volcanic, the red colour expressing lava and scoriæ.

The Fluvia, which flows near the town of Olot, has cut to the depth of only 40 feet through the lavas of the plain before mentioned. The bed of the river is hard basalt; and at the bridge of Santa Madalena are seen two distinct lava-currents, one above the other, separated by a horizontal bed of scoriæ eight feet thick.

In one place, to the south of Olot, the even surface of the plain is broken by a mound of lava, called the "Bosque de Tosca," the upper part of which is scoriaceous, and covered with enormous heaps of fragments of basalt more or less porous. Between the numerous hummocks thus formed are deep cavities, having the appearance of small craters. The whole precisely resembles some of the modern currents of Etna, or that of Côme, near Clermont; the last of which, like the Bosque de Tosca, supports only a scanty vegetation.

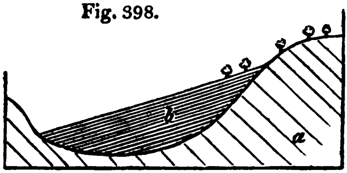
Most of the Catalonian volcanos are as entire as those in the neighbourhood of Naples, or on the flanks of Etna. One of these figured in the plate, called Montsacopa, is of a very regular form, and has a circular depression or crater at the summit. It is chiefly made up of red scoriæ, undistinguishable from that of the minor cones of Etna. The neighbouring hills of Olivet and

Garrinada, also figured in the plate, are of similar composition and shape. The largest crater of the whole district occurs farther to the east of Olot, and is called Santa Margarita. It is 455 feet deep, and about a mile in circumference. Like Astroni, near Naples, it is richly covered with wood, wherein game of various kinds abounds.

Although the volcanos of Catalonia have broken out through sandstone, shale, and limestone, as have those of the Eifel, in Germany, to be described in the sequel, there is a remarkable difference in the nature of the ejections composing the cones in these two regions. In the Eifel, the quantity of pieces of sandstone and shale thrown out from the vents is often so immense as far to exceed in volume the scoriæ, pumice, and lava; but I sought in vain in the cones near Olot for a single fragment of any extraneous rock; and Don Francisco Bolos, an eminent botanist of Olot, informs me that he has never been able to detect any. Volcanic sand and ashes are not confined to the cones, but have been sometimes scattered by the wind over the country, and drifted into narrow valleys, as is seen between Olot and Cellent, where the annexed section is exposed. The light cindery volcanic matter rests in thin regular layers, just as it alighted on the slope formed by the solid conglomerate. No flood could have

passed through the valley since the scoriæ fell, or these would have been for the most part removed.

Fig. 398.

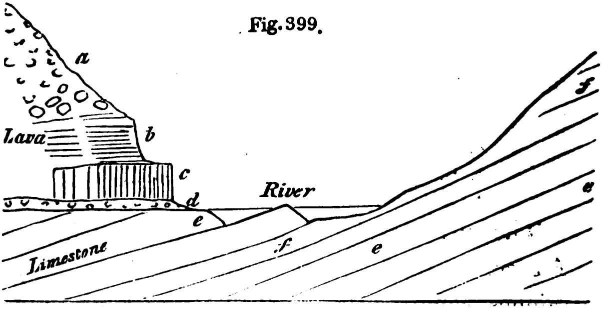


a. secondary conglomerate.
b. thin seams of volcanic sand and scoriæ.

The currents of lava in Catalonia, like those of Auvergne, the Vivarais, Iceland, and all mountainous countries, are of considerable depth in narrow defiles, but spread out into comparatively thin sheets in places where the valleys widen. If a river has flowed on nearly level ground, as in the great plain near Olot, the water has only excavated a channel of slight depth; but where the declivity is great, the stream has cut a deep section, sometimes by penetrating directly through the central part of a lava-current, but more frequently by passing between the lava and the secondary rock which bounds the valley. Thus, in the accompanying section, at the bridge of Cellent, six miles east of Olot, we see the lava on one side of the small stream; while the inclined stratified rocks constitute the channel and opposite bank. The upper part of the lava at that

place, as is usual in the currents of Etna and Vesuvius, is scoriaceous; farther down it becomes less porous, and assumes a spheroidal structure;

Fig. 399.



Section above the bridge of Cellent.

a. Scoriaceous lava.
b. Schistose basalt.
c. Columnar basalt.
d. Scoria, vegetable soil, and alluvium.
e. Nummulitic limestone.
f. Micaceous grey sandstone.

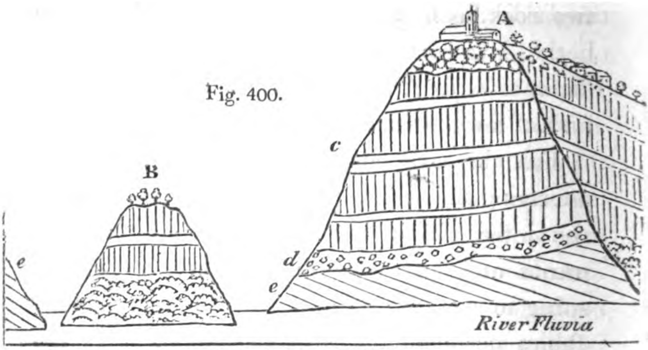
still lower it divides in horizontal plates, each about two inches in thickness, and is more compact. Lastly, at the bottom is a mass of prismatic basalt about five feet thick. The vertical columns often rest immediately on the subjacent secondary rocks; but there is sometimes an intervention of such sand and scoriæ as cover the country during volcanic eruptions, and which when unprotected, as here, by superincumbent lava, is washed away from the surface of the land. Sometimes, the bed, *d*, contains a few pebbles and angular fragments of rock; in other places fine earth, which may have constituted an ancient vegetable soil.

In several localities, beds of sand and ashes are interposed between the lava and subjacent stratified rock, as may be seen if we follow the course of the lava-current which descends from Las Planas towards Amer, and stops two miles short of that town. The river there has often cut through the lava, and through eighteen feet of underlying limestone. Occasionally an alluvium, several feet thick, is interspersed between the igneous and marine formation; and it is interesting to remark that in this, as in other beds of pebbles occupying a similar position, there are no rounded fragments of lava; whereas in the most modern gravel-beds of rivers of this country, volcanic pebbles are abundant.

The deepest excavation made by a river through lava, which I observed in this part of Spain, is that seen in the bottom of a valley near San Feliu de Palleróls, opposite the Castell de Stolles. The lava there has filled up the bottom of a valley, and a narrow ravine has been cut through it to the depth of one hundred feet. In the lower part the lava has a columnar structure. A great number of ages were probably required for the erosion of so deep a ravine; but we have no reason to infer that this current is of higher antiquity than those of the plain near Olot. The fall of the ground, and consequent velocity of the stream, being in this case greater, a more con-

siderable volume of rock may have been removed in the same time.

Fig. 400.



Section at Castell Follit.

A. Church and town of Castell Follit, overlooking precipices of basalt.

B. Small island, on each side of which branches of the river Teronel flow to meet the Fluvia.

c. Precipice of basaltic lava, chiefly columnar, about 130 feet in height.

d. Ancient alluvium, underlying the lava current.

e. Inclined strata of secondary sandstone.

I shall describe one more section to elucidate the phenomena of this district. A lava-stream, flowing from a ridge of hills on the east of Olot, descends a considerable slope, until it reaches the valley of the river Fluvia. Here, for the first time, it comes in contact with running water, which has removed a portion, and laid open its internal structure in a precipice about 130 feet in height, at the edge of which stands the town of Castell Follit.

By the junction of the rivers Fluvia and Teronel the mass of lava has been cut away on two sides; and the insular rock B (Fig. 400.) has been left, which was probably never so high as the cliff A, as it may have constituted the lower part of the sloping side of the original current.

From an examination of the vertical cliffs, it appears that the upper part of the lava on which the town is built is scoriaceous, passing downwards into a spheroidal basalt; some of the huge spheroids being no less than six feet in diameter. Below this is a more compact basalt with crystals of olivine. There are in all about four distinct ranges of prismatic basalt, separated by thinner beds not columnar, and some of which are schistose. The whole mass rests on alluvium, ten or twelve feet in thickness, composed of pebbles of limestone and quartz, but without any intermixture of igneous rocks; in which circumstance alone it appears to differ from the modern gravel of the Fluvia.

Bufadors.—The volcanic rocks near Olot have often a cavernous structure, like some of the lavas of Etna; and in many parts of the hill of Batet, in the environs of the town, the sound returned by the earth, when struck, is like that of an archway. At the base of the same hill are the mouths of several subterranean caverns, about twelve in number, which are called in the country

"bufadors," from which a current of cold air issues during summer, but which in winter is said to be scarcely perceptible. I visited one of these bufadors in the beginning of August, 1830, when the heat of the season was unusually intense, and found a cold wind blowing from it; which may easily be explained, for as the external air, when rarefied by heat, ascends, the pressure of the colder and heavier air of the caverns in the interior of the mountain causes it to rush out to supply its place.

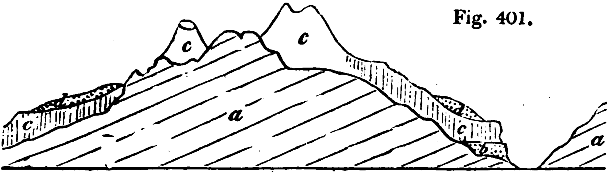
In regard to the age of these Spanish volcanos, attempts have been made to prove, that in this country, as well as in Auvergne and the Eifel, the earliest inhabitants were eye-witnesses to the volcanic action. In the year 1421, it is said, when Olot was destroyed by an earthquake, an eruption broke out near Amer, and consumed the town. The researches of Don Francisco Bolos have, I think, shown, in the most satisfactory manner, that there is no good historical foundation for the latter part of this story; and any geologist who has visited Amer must be convinced that there never was any eruption on that spot. It is true that, in the year above mentioned, the whole of Olot, with the exception of a single house, was cast down by an earthquake; one of those shocks which, at distant intervals during the last five centuries, have shaken the

Pyrenees, and particularly the country between Perpignan and Olot, where the movements, at the period alluded to, were most violent.

The annihilation of the town may, perhaps, have been due to the cavernous nature of the subjacent rocks; for Catalonia is beyond the line of those European earthquakes which have, within the period of history, destroyed towns throughout extensive areas.

As we have no historical records, then, to guide us in regard to the extinct volcanos, we must appeal to geological monuments. The annexed diagram will present to the reader, in a synoptical form, the results obtained from numerous sections.

Fig. 401.



Superposition of rocks in the volcanic district of Catalonia.

a. Sandstone and nummulitic limestone.
b. Older alluvium without volcanic pebbles.
c. Cones of scoriæ and lava. *d.* Newer alluvium.

The more modern alluvium, *d*, is partial, and has been formed by the action of rivers and floods upon the lava; whereas the older gravel, *b*, was strewed over the country before the volcanic eruptions. In neither have any organic remains

been discovered; so that we can merely affirm, as yet, that the volcanos broke out after the elevation of some of the newest rocks of the secondary series, and before the formation of an alluvium, *d*, of unknown date. The integrity of the cones merely shows that the country has not been agitated by violent earthquakes, or subjected to the action of any great transient flood since their origin.

East of Olot, on the Catalonian coast, marine tertiary strata occur, which, near Barcelona, attain the height of about five hundred feet. From the shells which I collected, these strata appear to correspond in age with the Subapennine beds; and it is not improbable that their upheaval from beneath the sea took place during the period of volcanic eruption round Olot. In that case these eruptions may have occurred at the close of the Older Pliocene era, but perhaps subsequently, for their age is at present quite uncertain.

Miocene period — Volcanic rocks of the Eifel. — The chronological relations of the volcanic rocks of the Lower Rhine and the Eifel are also involved in a considerable degree of ambiguity; but we know that some portion of them were coeval with the deposition of a tertiary formation, called "Brown-Coal" by the Germans, which I refer to the Miocene epoch.

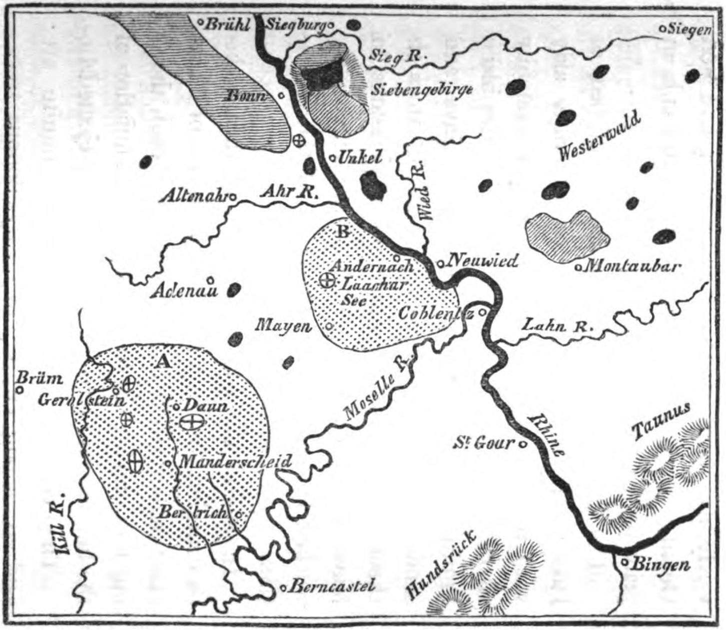


Fig. 402.

English Miles.

1 2 3 4 5

Volcanic District { A. of the Upper Eifel. B. of the Lower Eifel.

Trachyte.

Points of eruption, with craters and scoriæ.

Basalt.

Brown-coal.

N. B. The country in that part of the map which is left blank is composed of inclined Silurian and Devonian rocks.

This Brown-Coal is seen on both sides of the Rhine, in the neighbourhood of Bonn, resting unconformably on highly inclined and vertical strata of Silurian and Devonian rocks. Its position, and the space occupied by the volcanic rocks, both of the Westerwald and Eifel, will be seen by referring to the annexed map (fig. 402.), for which I am indebted to Mr. Horner, whose residence in the country has enabled him to verify the maps of M. M. Noeggerath and Von Oeynhausen, from which that now given has been principally compiled.

The Brown-Coal formation consists of beds of loose sand, sandstone, and conglomerate, clay with nodules of clay ironstone, and occasionally silex. Layers of light brown and sometimes black lignite are interstratified with the clays and sands, and often irregularly diffused through them. They contain numerous impressions of leaves and stems of trees, and are extensively worked for fuel, whence the name of the formation.

In several places layers of trachytic tuff are interstratified, and in these tuffs are leaves of plants identical with those found in the brown coal, showing that, during the period of the accumulation of the latter, some volcanic products were ejected.

The varieties of wood in the lignite are said to belong entirely to dicotyledonous trees;

but among the impressions of leaves, collected by Mr. Horner, some were referred by Mr. Lindley to a palm, perhaps of the genus *Chamærops*, and others resembled the *Cinnamomum dulce*, and *Podocarpus macrophylla*, which would also indicate a warm climate.*

The other organic remains of the brown-coal are principally fishes; they are found in a bituminous shale, called paper-coal, from being divisible into extremely thin leaves. The individuals are very numerous; but they appear to belong to about five species, which M. Agassiz informs me are all extinct, and hitherto peculiar to this brown coal. They belong to the freshwater genera *Leuciscus*, *Aspius*, and *Perca*. The remains of frogs also, of an extinct species, have been discovered in the paper-coal; and a complete series may be seen in the museum at Bonn, from the most imperfect state of the tadpole to that of the full-grown animal. With these a salamander, scarcely distinguishable from the recent species, has been found, and several remains of insects.

The Brown-Coal was evidently a freshwater formation; but fossil shells have been scarcely ever found in it; although near Marienforst, in the vicinity of Bonn, large blocks have been met with of a white opaque chert, containing numerous casts of freshwater shells, which appear to belong

* Trans. of Geol. Soc., 2d ser. vol. v.

to *Planorbis rotundatus* and *Limnea longiscata*, two species common both to the Eocene and Miocene periods, but which have not been found in any newer deposits. It is very probable that the brown-coal may be connected in age with those fluvio-marine formations which are found in higher parts of the valley of the Rhine, as at Mayence before mentioned.

A vast deposit of gravel, chiefly composed of pebbles of white quartz, but containing also a few fragments of other rocks, lies over the Brown-Coal formation, forming sometimes only a thin covering, at others attaining a thickness of more than 100 feet. This gravel is very distinct in character from that now forming the bed of the Rhine. It is called "Kiesel gerolle" by the Germans, often reaches great elevations, and is covered in several places with volcanic ejections. It is evident that the country has undergone great changes in its physical geography since this gravel was formed; for its position has scarcely any relation to the existing drainage of the country, and all the more modern volcanic rocks of the same region are posterior to it in date.

Some of the newest beds of volcanic sand, pumice, and scoriæ are interstratified near Andernach and elsewhere with the loam called loess, which was before described as being full of land and freshwater shells of recent species, and referable to the Post-

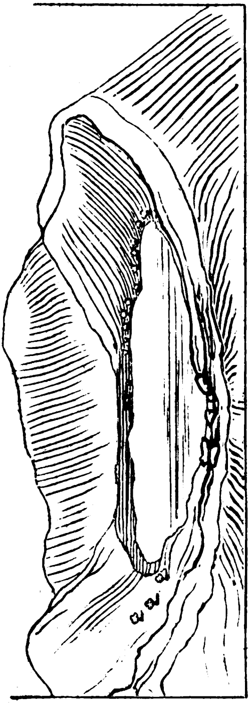
pliocene period. I have before hinted (see Chap. XI.) that this intercalation of volcanic matter between beds of loess may possibly be explained without supposing the last eruptions of the Lower Eifel to have taken place so recently as the era of the deposition of the loess; but farther researches should be directed to the investigation of this curious point.

The igneous rocks of the Westerwald, and of the mountains called the Siebengebirge, consist partly of basaltic and partly of trachytic lavas, the latter being in general the more ancient of the two. There are many varieties of trachyte, some of which are highly crystalline, resembling a coarse-grained granite, with large separate crystals of felspar. Trachytic tuff is also very abundant. These formations, some of which were certainly contemporaneous with the origin of the Brown-Coal, were the first of a long series of eruptions, the more recent of which happened when the country had acquired nearly all its present geographical features.

Newer volcanos of the Eifel.—Lake-craters.—As I recognized in the more modern volcanos of the Eifel characters distinct from any previously observed by me in those of France, Italy, or Spain, I shall briefly describe them. The fundamental rocks of the district are grey and red sandstones and shales, with some associated limestones, replete with

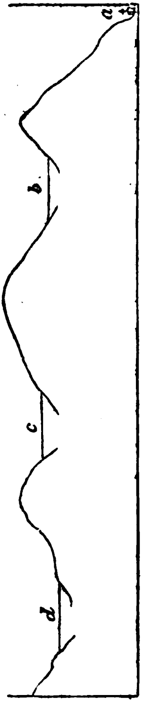
fossils of the Devonian or Old Red sandstone group. The volcanos broke out in the midst of these inclined strata, and when the present systems of hills and valleys had already been formed. The eruptions occurred sometimes at the bottom of deep valleys, sometimes on the summit of hills, and frequently on

Fig. 403.



The Gemunder Maar.

Fig. 404.



a. Village of Gemund. *c.* Weinfelder Maar.
b. Gemunder Maar. *d.* Schalkenmehren Maar.

intervening platforms. In travelling through this district we often fall upon them most unexpectedly, and may find ourselves on the very edge of a

crater before we had been led to suspect that we were approaching the site of any igneous outburst. Thus, for example, on arriving at the village of Gemund, immediately south of Daun, we leave the stream, which flows at the bottom of a deep valley in which strata of sandstone and shale crop out. We then climb a steep hill, on the surface of which we see the edges of the same strata dipping inwards towards the mountain. When we have ascended to a considerable height, we see fragments of scoriæ sparingly scattered over the surface; till, at length, on reaching the summit, we find ourselves suddenly on the edge of a *tarn*, or deep circular lake-basin.

This, which is called the Gemunder Maar, is the first of three lakes which are in immediate contact, the same ridge forming the barrier of two neighbouring cavities (see Fig. 403.). On viewing the first of these, we recognize the ordinary form of a crater, for which we have been prepared by the occurrence of scoriæ scattered over the surface of the soil. But on examining the walls of the crater we find precipices of sandstone and shale which exhibit no signs of the action of heat; and we look in vain for those beds of lava and scoriæ, dipping in opposite directions on every side, which we have been accustomed to consider as characteristic of volcanic craters. As we proceed, however, to the opposite side of the lake, and after-

wards visit the craters *c* and *d* (Fig. 404.), we find a considerable quantity of scoriæ and some lava, and see the whole surface of the soil sparkling with volcanic sand, and strewed with ejected fragments of half-fused shale, which preserves its laminated texture in the interior, while it has a vitrified or scoriform coating.

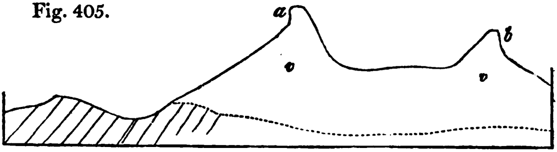
A few miles to the south of the lakes above mentioned occurs the Pulvermaar of Gillenfeld, an oval lake of very regular form, and surrounded by an unbroken ridge of fragmentary materials, consisting of ejected shale and sandstone, and preserving a uniform height of about 150 feet above the water. The side slope in the interior is at an angle of about forty-five degrees; on the exterior, of thirty-five degrees. Volcanic substances are intermixed very sparingly with the ejections, which in this place entirely conceal from view the stratified rocks of the country.*

The Meerfelder Maar is a cavity of far greater size and depth, hollowed out of similar strata; the sides presenting some abrupt sections of inclined secondary rocks, which in other places are buried under vast heaps of pulverized shale. I could discover no scoriæ amongst the ejected materials, but balls of olivine and other volcanic substances are mentioned as having been found.† This cavity,

* Scrope, Edin. Journ. of Sci., June, 1826, p. 145.
† Hibbert, Extinct Volcanos of the Rhine, p. 24.

which we must suppose to have discharged an immense volume of gas, is nearly a mile in diameter, and is said to be more than one hundred fathoms deep. In the neighbourhood is a mountain called the Mosenberg, which consists of red sandstone and shale in its lower parts, but supports on its summit a triple volcanic cone, while a distinct current of lava is seen descending the flanks of the mountain. The edge of the crater of the largest cone reminded me much of the form and characters of that of Vesuvius; but I was much struck with the precipitous and almost overhanging wall which the scoriæ presented towards the exterior, as at *a b* (Fig. 405.); which I can

Fig. 405.



Stratified rocks. *v.* Volcanic.

Outline of Mosenberg, Upper Eifel.

only explain by supposing that fragments of red-hot lava, as they fell round the vent, were cemented together into one compact mass, in consequence of continuing to be in a half-melted state.

If we pass from the Upper to the Lower Eifel, from A to B (see map, p. 279.), we find the celebrated lake-crater of Laach, which has a greater resemblance than any of those before mentioned

to the Lago di Bolsena, and others in Italy — being surrounded by a ridge of gently sloping hills, composed of loose tuffs, scoriæ, and blocks of a variety of lavas.

One of the most interesting volcanos on the left bank of the Rhine is called the Roderberg. It forms a circular crater nearly a quarter of a mile in diameter, and one hundred feet deep, now covered with fields of corn. The highly inclined strata of ancient sandstone and shale rise even to the rim of one side of the crater; but they are overspread by quartzose gravel, and this again is covered by volcanic scoriæ and tufaceous sand. The opposite wall of the crater is composed of cinders and scorified rock, like that at the summit of Vesuvius. It is quite evident that the eruption in this case burst through the sandstone and alluvium which immediately overlies it; and I observed some of the quartz pebbles mixed with scoriæ on the flanks of the mountain, as if they had been cast up into the air, and had fallen again with the volcanic ashes. I have already observed, that a large part of this crater has been filled up with loess.*

The most striking peculiarity of a great many of the craters above described, is the absence of any signs of alteration or torrefaction in their

* See Vol. I. p. 263.

walls, when these are composed of regular strata of ancient sandstone and shale. It is evident that the summits of hills formed of the above-mentioned stratified rocks have, in some cases, been carried away by gaseous explosions, while at the same time no lava, and often a very small quantity only of scoriæ, has escaped from the newly formed cavity. There is, indeed, no feature in the Eifel volcanos more worthy of note, than the proofs they afford of very copious aëriform discharges, unaccompanied by the pouring out of melted matter, except, here and there, in very insignificant volume. I know of no other extinct volcanos where gaseous explosions of such magnitude have been attended by the emission of so small a quantity of lava. Yet I looked in vain in the Eifel for any appearances which could lend support to the hypothesis, that the sudden rushing out of such enormous volumes of gas had ever lifted up the stratified rocks immediately around the vent, so as to form conical masses, having their strata dipping outwards on all sides from a central axis, as is assumed in the theory of elevation craters, which I have fully discussed in another work.*

Trass. — In the Lower Eifel, eruptions of trachytic lava preceded the emission of currents

* See Principles of Geology.

of basalt, and immense quantities of pumice were thrown out wherever trachyte issued. The tufaceous alluvium called *trass*, which has covered large areas in this region and choked up some valleys now partially re-excavated, is unstratified. Its base consists almost entirely of pumice, in which are included fragments of basalt and other lavas, pieces of burnt shale, slate, and sandstone, and numerous trunks and branches of trees. If this trass was formed during the period of volcanic eruptions, it may perhaps have originated in the manner of the moya of the Andes.

We may easily conceive that a similar mass might now be produced, if a copious evolution of gases should occur in one of the lake basins. The water might remain for weeks in a state of violent ebullition, until it became of the consistency of mud, just as the sea continued to be charged with red mud round Graham's Island, in the Mediterranean, in the year 1831. If a breach should then be made in the side of the cone, the flood would sweep away great heaps of ejected fragments of shale and sandstone, which would be borne down into the adjoining valleys. Forests might be torn up by such a flood; and thus the occurrence of the numerous trunks of trees dispersed irregularly through the trass, can be explained.

Hungary. — M. Beudant, in his elaborate work on Hungary, describes five distinct groups of vol-

canic rocks, which, although nowhere of great extent, form striking features in the physical geography of that country, rising as they do abruptly from extensive plains composed of tertiary strata. They may have constituted islands in the ancient sea, as Santorin and Milo now do in the Grecian Archipelago; and M. Beudant has remarked that the mineral products of the last-mentioned islands resemble remarkably those of the Hungarian extinct volcanos, where many of the same minerals, as opal, calcedony, resinous silex (*silex resinite*), pearlite, obsidian, and pitchstone abound.

The Hungarian lavas are chiefly felspathic, consisting of different varieties of trachyte; many are cellular, and used as millstones; some so porous and even scoriform as to resemble those which have issued in the open air. Pumice occurs in great quantity; and there are conglomerates, or rather breccias, wherein fragments of trachyte are bound together by pumiceous tuff, or sometimes by silex.

It is probable that these rocks were permeated by the waters of hot springs, impregnated, like the Geysers, with silica; or, in some instances, perhaps, by aqueous vapours, which, like those of Lancerote, may have precipitated hydrate of silica.

By the influence of such springs or vapours the trunks and branches of trees washed down during

floods, and buried in tuffs on the flanks of the mountains, are supposed to have become silicified. It is scarcely possible, says M. Beudant, to dig into any of the pumiceous deposits of these mountains without meeting with opalized wood, and sometimes entire silicified trunks of trees of great size and weight.

It appears from the species of shells collected principally by M. Boué, and examined by M. Deshayes, that the fossil remains imbedded in the volcanic tuffs, and in strata alternating with them in Hungary, are of the Miocene type, and not identical, as was formerly supposed, with the fossils of the Paris basin.

CHAPTER XXXI.

ON THE DIFFERENT AGES OF THE VOLCANIC ROCKS — *continued.*

Volcanic rocks of the Miocene period, continued—Auvergne—Mont Dor — Breccias and alluviums of Mont Perrier, with bones of quadrupeds—River dammed up by lava current—Range of minor cones from Auvergne to the Vivarais — Monts Dome — Puy de Côme — Puy de Pariou—Cones not denuded by general flood — Velay — Bones of quadrupeds buried in scoriæ — Cantal — Eocene volcanic rocks — Tuffs near Clermont — Hill of Gergovia — Trap of Cretaceous period — Oolitic period — New Red sandstone period—Carboniferous period—Old Red Sandstone period — "Rock and Spindle" near St. Andrew's — Silurian period—Cambrian volcanic rocks.

Miocene Volcanic Rocks. — Auvergne. — THE extinct volcanos of Auvergne and Cantal in Central France seem to have commenced their eruptions in the Eocene period, but to have been most active during the Miocene era. I have already alluded to the grand succession of events, of which there is evidence in Auvergne since the last retreat of the sea (see Vol. I. p. 362.).

The earliest monuments of the tertiary period in that region are lacustrine deposits of great thickness, in the lowest conglomerates of

which are rounded pebbles of quartz, mica-schist, granite, and other non-volcanic rocks, but without the slightest intermixture of igneous products. To these conglomerates succeed argillaceous and calcareous marls containing Eocene shells, in which some feeble signs of volcanic action begin to show themselves. In the higher part of the series are freshwater marls and limestones, which alternate with volcanic tuff, and in them some fossils of the Miocene period appear. After the filling up or drainage of the ancient lakes, huge piles of trachytic and basaltic rocks, with volcanic breccias, accumulated to a thickness of several thousand feet, and were superimposed upon granite, or the contiguous lacustrine strata. The greater portion of these igneous rocks appear to have originated during the Miocene period, and extinct quadrupeds of that era, belonging to the genera Mastodon, Rhinoceros, and others, were buried in ashes and beds of alluvial sand and gravel, which owe their preservation to overspreading sheets of lava.

In Auvergne the most ancient and conspicuous of the volcanic masses is Mont Dor, which rests immediately on the granitic rocks standing apart from the freshwater strata.* This great mountain rises suddenly to the height of several thousand

* See the map, Vol. I. p. 361.

feet above the surrounding platform, and retains the shape of a flattened and somewhat irregular cone, all the sides sloping more or less rapidly, until their inclination is gradually lost in the high plain around. This cone is composed of layers of scoriæ, pumice-stones, and their fine detritus, with interposed beds of trachyte and basalt, which descend often in uninterrupted sheets, till they reach and spread themselves round the base of the mountain.* Conglomerates, also, composed of angular and rounded fragments of igneous rocks, are observed to alternate with the above; and the various masses are seen to dip off from the central axis, and to lie parallel to the sloping flanks of the mountain.

The summit of Mont Dor terminates in seven or eight rocky peaks, where no regular crater can now be traced, but where we may easily imagine one to have existed, which may have been shattered by earthquakes, and have suffered degradation by aqueous agents. Originally, perhaps, like the highest crater of Etna, it may have formed an insignificant feature in the great pile, and may frequently have been destroyed and renovated.

According to some geologists, this mountain, as well as Vesuvius, Etna, and all large volcanos, has derived its dome-like form not from the

* Scrope's Central France, p. 98.

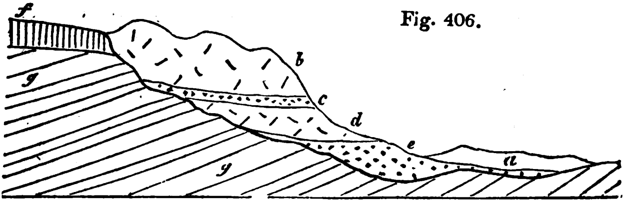
preponderance of eruptions from one or more central points, but from the upheaval of horizontal beds of lava and scoriæ. I have explained my reasons for objecting to this view in the Principles of Geology. Nevertheless we may expect to find that during the long series of eruptions required to give rise to so vast a pile of volcanic matter, much dislocation and upheaval took place; and during the distention of the mass some beds of lava and scoriæ may have acquired a greater, others a less, inclination, than that which at first belonged to them.*

Respecting the age of the great mass of Mont Dor, we cannot come at present to any positive decision, because no organic remains have yet been found in the tuffs, except impressions of the leaves of trees of species not yet determined. We may certainly conclude, that the earliest eruptions were posterior in origin to those grits and conglomerates of the freshwater formation of the Limagne which contain no pebbles of volcanic rocks. But it will be shewn that some eruptions took place before the great lakes were drained; while others occurred after the desiccation of those lakes, and when deep valleys had already been excavated through freshwater strata. Even some trachytic breccias, such as those of

* See Principles, particularly 6th ed., vol. ii. chap. 13.

Mont Perrier, for example, which precisely resemble others in Mont Dor, and doubtless descended from it, are found on the flanks of a valley which was first hollowed out of the Eocene strata, then filled with breccia and alluvium, and afterwards, to a great extent, re-excavated. The annexed drawing will explain the position of the breccias *b* and *d* above alluded to, and of two associated beds of ancient alluvium, *c* and *e*, in which the remains of quadrupeds

Fig. 406.



Position of the Volcanic breccias and alluviums of Mont Perrier, Auvergne.

Descending series.

a. Newer alluvium. *b.* Second trachytic breccia.
c. Second Miocene alluvium with bones.
d. First trachytic breccia.
e. First Miocene alluvium with bones.
f. Compact basalt. *g.* Eocene lacustrine strata.

characteristic of the Miocene period have been obtained. In order to account for the situation of these masses, we must suppose that after the tertiary strata *g*, covered by the basaltic lava *f*, had been exposed to aqueous denudation, the alluvium *e* had accumulated in a valley. The remains of quadrupeds then inhabiting the

country, and which had been drowned, perhaps, during floods, were buried in silt, gravel, and sand *e*. The trachytic breccia *d* was then superimposed; this breccia is an aggregate of shapeless and angular fragments of trachyte, cemented by volcanic tuff and pumice, precisely resembling some of the breccias which enter into the composition of the neighbouring Mont Dor, and which are very analogous to some found on Etna. Upon this rests another alluvium, *c*, which also contains the bones of Miocene species, and this is covered by another enormous mass of tufaceous breccia. The breccias have probably resulted from the sudden rush of large bodies of water down the sides of an elevated volcano at its moments of eruption, perhaps when snow was melted by lava. Such floods occur in Iceland, sweeping away loose blocks of lava and ejections surrounding the crater, and then strewing the plains with fragments of igneous rocks, enveloped in mud or "moya." The abrupt escarpment presented by the above-described beds, *b*, *c*, *d*, *e*, towards the valley of the Couze, must have been caused by subsequent erosion, which has carried away a large portion of those masses.*

* For an account of the position and age of the volcanic breccias of Mont Perrier and Boulade, see Lyell and Murchison on the Beds of Mont Perrier, Ed. New Phil. Journ., July, 1829, p. 15.

The newest alluvium (*a*) may also serve to represent the position occupied farther up the same valley by the most modern lava stream of the Puy de Tartaret, by connecting which with the section now under consideration, we have before us the signs of a remarkable succession of volcanic operations. The first of these produced the ancient columnar basalt (*f*); the second, the trachytic breccia (*d*); the third, the breccia (*b*); and the fourth, the most modern lava (*a*); which last, although comparatively modern, may still, as we shall afterwards see, be of indefinite antiquity.

In the alluviums *c* and *e*, MM. Croizet, Jobert, Chabriol, and Bouillet have discovered the remains of about forty species of extinct mammalia, the greater part of which are peculiar as yet to this locality; but some of them are characteristic of the Miocene period, being common to the faluns of Touraine, and associated in other localities with marine Miocene strata. Among these species may be enumerated *Mastodon minor* and *M. arvernensis*, *Hippopotamus major*, *Rhinoceros leptorhinus*, and *Tapir arvernensis*. The *Elephas primigenius*, a species common to so many tertiary periods, is also stated to accompany the rest. In some cases the remains are not sufficiently characteristic to indicate the exact species, but the following genera can be determined: —

The boar, horse, ox, hyæna (two species), felis (three or four), bear (three), deer (many species), canis, otter, beaver, hare, and water-rat.*

The great mass of Mont Dor must have resulted from a long series of eruptions, by which melted matter was poured forth again and again from one vent, or from several neighbouring orifices. But here, as on Etna, there were numerous minor cones, which were thrown up in the valleys and ravines formed by earthquakes and floods in the course of ages, on the flanks, and at the base of the great volcano. Thus in the valley of Chambon, the boundary precipices of which are formed by ancient columnar trachytes and basalts, the Puy de Tartaret has been cast up, so as to obstruct and dam up the channel of the river Couze with its cone of loose scoriæ and its lava-current, which has flowed down the valley for thirteen miles. The barrier thus thrown across the ancient course of the stream gave rise to a lake which exists to this day; but although the river has been unable to cut out a new channel of sufficient depth to drain this lake, it has at several points below its outlet, eaten into the lava to such a depth as to lay open a bed of river gravel which existed before the lava of Tartaret,

* Recherches sur les Oss. Foss. du Dépt. du Puy de Dome, 4to. 1828. Essai Géol. et Minéral. sur les Environs d'Issoire, Dépt. du Puy de Dome, folio, 1827.

now incumbent upon it, was poured out, in the same manner as was explained in sections, Fig. 400. p. 274. and Vol. I. p. 167.

In Central France there are several hundred minor cones, like that of Tartaret, a great number of which, like Monte Nuovo, near Naples, may have been principally due to a single eruption. Most of these cones range in a linear direction from Auvergne to the Vivarais, and they were faithfully described so early as the year 1802, by M. de Montlosier. They have given rise chiefly to currents of basaltic lava. Those of Auvergne called the Monts Dome, placed on a granitic platform, form an irregular ridge (see Fig. 369.), about eighteen miles in length and two in breadth. They are usually truncated at the summit, where the crater is often preserved entire, the lava having issued from the base of the hill. But frequently the crater is broken down on one side, where the lava has flowed out. The hills are composed of loose scoriæ, blocks of lava, lapilli, and pozzuolana, with fragments of trachyte and granite.

The lavas, like that of Tartaret already mentioned, may be often traced from the crater to the nearest valley, where they usurp the channel of the river, which has frequently excavated a deep ravine through the basalt. We have thus an opportunity of contrasting the enormous degradation

which the solid and massive rock has suffered by aqueous erosion, and the integrity of the cone of sand and ashes which has, in the mean time, remained uninjured on the neighbouring platform, where it was placed beyond the reach of the power of running water. Had any great diluvial rush of waters expended its fury on the more elevated parts of this district, such cones must have been greatly modified in form, if not entirely swept away.

Puy de Côme.—The Puy de Côme and its lava current, near Clermont, may be mentioned as one of the numerous illustrations of the phenomenon here alluded to. This conical hill rises from the granitic platform, at an angle of about 40°, to the height of more than 900 feet. Its summit presents two distinct craters, one of them with a vertical depth of 250 feet. A stream of lava takes its rise at the western base of the hill, instead of issuing from either crater, and descends the granitic slope towards the present site of the town of Pont Gibaud. Thence it pours in a broad sheet down a steep declivity into the valley of the Sioule, filling the ancient river-channel for the distance of more than a mile. The Sioule, thus dispossessed of its bed, has worked out a fresh one between the lava and the granite of its western bank; and the excavation has disclosed,

in one spot, a wall of columnar basalt about 50 feet high.*

The excavation of the ravine is still in progress, every winter some columns of basalt being undermined and carried down the channel of the river, and in the course of a few miles rolled to sand and pebbles. Meanwhile the cone of Côme remains stationary, its loose materials being protected by a dense vegetation, and the hill standing on a ridge not commanded by any higher ground whence floods of rain-water may descend.

Puy Rouge.—At another point, farther down the course of the Sioule, we find a second illustration of the same phenomenon in the Puy Rouge, a conical hill to the north of the village of Pranal. The cone is composed entirely of red and black scoriæ, tuff, and volcanic bombs. On its western side there is a worn-down crater, whence a powerful stream of lava has issued, and flowed into the valley of the Sioule. The river has since excavated a ravine through the lava and subjacent gneiss, to the depth of 400 feet.

On the upper part of the precipice forming the left side of this ravine, we see a great mass of black and red scoriaceous lava; below this a thin bed of gravel, evidently an ancient river-bed, now at an elevation of fifty feet above the channel

* Scrope's Central France, p. 60., and plate.

of the Sioule. The gravel again rests upon gneiss, which has been eroded to the depth of 50 feet. It is quite evident in this case, that, while the basalt was gradually undermined and carried away by the force of running water, the cone whence the lava issued escaped destruction, because it stood upon a platform of gneiss several hundred feet above the level of the valley in which the force of running water was exerted.

Puy de Pariou.—The brim of the crater of the Puy de Pariou, near Clermont, is so sharp, and has been so little blunted by time, that it scarcely affords room to stand upon. This and other cones in an equally remarkable state of integrity have stood, I conceive uninjured, not *in spite* of their loose porous nature, as might at first be naturally supposed, but in consequence of it. No rills can collect where all the rain is instantly absorbed by the sand and scoriæ, as is remarkably the case on Etna; and nothing but a water-spout breaking directly upon the Puy de Pariou could carry away a portion of the hill, so long as it is not rent or engulphed by earthquakes.

Hence it is conceivable that even those cones which have the freshest aspect, and most perfect shape, may lay claim to an indefinite antiquity. Dr. Daubeny has justly observed, that had any of these volcanos been in a state of activity in the age of Julius Cæsar, that general, who encamped

upon the plains of Auvergne, and laid siege to its principal city (Gergovia, near Clermont), could hardly have failed to notice them. Had there been any record of their eruptions in the time of Pliny or Sidonius Apollinaris, the one would scarcely have omitted to make mention of it in his Natural History, nor the other to introduce some allusion to it among the descriptions of this his native province. This poet's residence was on the borders of the Lake Aidat, which owed its very existence to the damming up of a river by one of the most modern lava-currents.*

The ruins of several Roman bridges, and of the Roman baths at Royat, confirm the conclusion that no sensible alteration has taken place in the physical geography of the district, not even in the chasms excavated through the newest lavas since ages historically remote. We have no data at present for presuming that any one of the Auvergne cones has been produced within the last four or five thousand years; and the same may be said of those of Velay; and, until the bones of men or articles of human workmanship are found buried under some of their lavas, instead of the remains of extinct animals, which alone have hitherto been met with, we are justified in regarding it as probable that the latest of the vol-

* Daubeny on Volcanos, p. 14.

canic eruptions may have occurred during the Miocene period.

Velay. — The observations of M. Bertrand de Doue have not yet established that any of the most ancient volcanos of Velay were in action during the Eocene period. There are beds of gravel in Velay as in Auvergne, covered by lava at different heights above the channels of the existing rivers. In the highest and most ancient of these alluviums the pebbles are exclusively of granitic rocks; but in the newer, which are found at lower levels, and which originated when the valleys had been cut to a greater depth, an intermixture of volcanic rocks has been observed.

At St. Privat d'Allier a bed of volcanic scoriæ and tuff was discovered by Dr. Hibbert, inclosed between two sheets of basaltic lava; and in this tuff were found the bones of several quadrupeds, some of them adhering to masses of slaggy lava. Among other animals were *Rhinoceros leptorhinus*, *Hyæna spelæa*, and a species allied to the spotted hyæna of the Cape, together with four undetermined species of deer.* The manner of the occurrence of these bones reminds us of the recently published accounts of an eruption of Coseguina,

* Edin. Journ. of Sci., No. iv. N. S. p. 276. Figures of some of these remains are given by M. Bertrand de Doue, Ann. de la Soc. d'Agricult. de Puy, 1828.

1835, in Central America (see p. 244.), during which hot cinders and scoriæ fell and scorched to death great numbers of wild and domestic animals and birds.

Plomb du Cantal. — In regard to the age of the igneous rocks of the Cantal, we can at present merely affirm, that they overlie the Eocene lacustrine strata of that country (see Map, Vol. I. p. 361.). They form a great dome-shaped mass, which has evidently been accumulated, like the cone of Etna, during a long series of eruptions. It is composed of trachytic, phonolitic, and basaltic lavas, tuffs, and conglomerates, or breccias, forming a mountain several thousand feet in height. Dikes also of phonolite, trachyte, and basalt are numerous, especially in the neighbourhood of the large cavity, probably once a crater, around which the loftiest summits of the Cantal are ranged circularly, few of them, except the Plomb du Cantal, rising far above the border or ridge of this supposed crater. A pyramidal hill, called the Puy Griou, occupies the middle of the cavity.* It is evident that the volcano of the Cantal broke out precisely on the site of the lacustrine deposit before described (Chap. XVI.), which had accumulated in a depression of a tract composed of micaceous schist. In the breccias, even to the very summit

* Mém. de la Soc. Géol. de France, tom. i. p. 175.

of the mountain, we find ejected masses of the freshwater beds, and sometimes fragments of flint, containing Eocene shells. Valleys radiate in all directions from the central heights of the mountain, increasing in size as they recede from those heights. Those of the Cer and Jourdanne, which are more than twenty miles in length, are of great depth, and lay open the geological structure of the mountain. No alternation of lavas with undisturbed Eocene strata has been observed, nor any tuffs containing freshwater shells, although some of these tuffs include fossil remains of terrestrial plants, said to imply several distinct restorations of the vegetation of the mountain in the intervals between great eruptions. On the northern side of the Plomb du Cantal, at La Vissiere, near Murat, is a spot, pointed out on the Map (Vol. I. p. 361.), where freshwater limestone and marl are seen covered by a thickness of about eight hundred feet of volcanic rock. Shifts are here seen in the strata of limestone and marl.*

Eocene period. — In treating of the lacustrine deposits of Central France, in the sixteenth chapter, it was stated that, in the arenaceous and pebbly group of the lacustrine basins of Auvergne, Cantal, and Velay, no volcanic pebbles had ever been detected, although massive piles of igneous

* See Lyell and Murchison, Ann. des Sci. Nat., Oct. 1829.

rocks are now found in the immediate vicinity. As this observation has been confirmed by minute research, we are warranted in inferring that the volcanic eruptions had not commenced when the older subdivisions of the freshwater groups originated.

In Cantal and Velay no decisive proofs have yet been brought to light that any of the igneous outbursts happened during the deposition of the freshwater strata; but there can be no doubt that in Auvergne some volcanic explosions took place before the drainage of the lakes, and at a time when the Eocene species of animals and plants still flourished. Thus, for example, at Pont du Chateau, near Clermont, a section is seen in a precipice on the right bank of the river Allier, in which beds of volcanic tuff alternate with a freshwater limestone, which is in some places pure, but in others spotted with fragments of volcanic matter, as if it were deposited while showers of sand and scoriæ were projected from a neighbouring vent.* This limestone contains *Helix Ramondi* and other shells of Eocene species. In reference to the chronological question, it is immaterial whether the volcanic sand was showered down from above, or drifted to the spot by a river; for the latter opinion must presuppose the country

* See Scrope's Central France, p. 21.

to have been covered with volcanic ejections during the Eocene period.

Another example occurs in the Puy de Marmont, near Veyres, where a freshwater marl alternates with volcanic tuff containing Eocene shells. The tuff or breccia in this locality is precisely such as is known to result from volcanic ashes falling into water, and subsiding together with ejected fragments of marl and other stratified rocks. These tuffs and marls are highly inclined, and traversed by a thick vein of basalt, which, as it rises in the hill, divides into two branches.

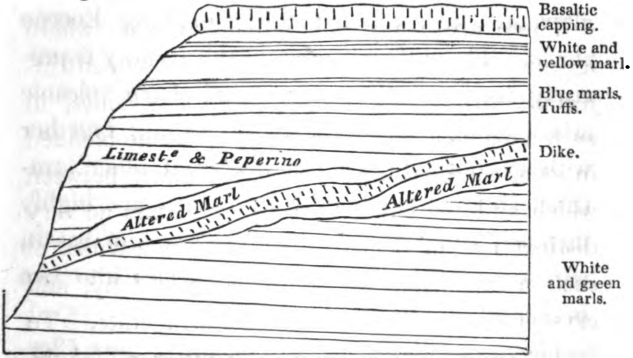
Gergovia.—The hill of Gergovia, near Clermont, affords a third example. I agree with MM. Dufrénoy and Jobert that there is no alternation here of a contemporaneous sheet of lava with freshwater strata, in the manner supposed by some other observers*; but the position and contents of some of the associated tuffs, prove them to have been derived from volcanic eruptions which occurred during the deposition of the lacustrine strata.

The bottom of the hill consists of slightly inclined beds of white and greenish marls, more than three hundred feet in thickness, intersected by a dike of basalt, which may be studied in the ravine

* See Scrope's Central France, p. 7.

above the village of Merdogne. The dike here cuts through the marly strata at a considerable angle, producing, in general, great alteration and

Fig. 407.



Hill of Gergovia.

confusion in them for some distance from the point of contact. Above the white and green marls, a series of beds of limestone and marl, containing freshwater shells, are seen to alternate with volcanic tuff. In the lowest part of this division, beds of pure marl alternate with compact fissile tuff, resembling some of the subaqueous tuffs of Italy and Sicily called *peperinos*. Occasionally fragments of scoriæ are visible in this rock. Still higher is seen another group of some thickness, consisting exclusively of tuff, upon which lie other marly strata intermixed with volcanic matter. An account of the precise species of fossils found in these strata would be highly

interesting, and enable us to decide whether the upper part of the great freshwater series does not indicate a passage from an Eocene to a Miocene fauna.

There are many points in Auvergne where igneous rocks have been forced by subsequent injection through clays and marly limestones, in such a manner that the whole has become blended in one confused and brecciated mass, between which and the basalt there is sometimes no very distinct line of demarcation. In the cavities of such mixed rocks we often find calcedony, and crystals of mesotype, stilbite, and arragonite. To formations of this class may belong some of the breccias immediately adjoining the dike in the hill of Gergovia; but it cannot be contended that the volcanic sand and scoriæ interstratified with the marls and limestones in the upper part of that hill were introduced, like the dike, subsequently, by intrusion from below. They must have been thrown down like sediment from water, and can only have resulted from igneous action, which was going on contemporaneously with the deposition of the lacustrine strata.

The reader will bear in mind that this conclusion agrees well with the proofs, adverted to in the sixteenth chapter, of the abundance of silex, travertin, and gypsum precipitated when the upper lacustrine strata were formed; for these

rocks are such as the waters of mineral and thermal springs might generate.

Cretaceous period.—Although we have no proof of volcanic rocks erupted in England during the deposition of the chalk and green-sand, it would be an error to suppose that no theatres of igneous action existed in the cretaceous period. M. Virlet, in his account of the geology of the Morea (p. 205.), has clearly shown that certain traps in Greece, called by him ophiolites, are of this date; as those, for example, which alternate conformably with cretaceous limestone and green-sand between Kastri and Damala in the Morea. They consist in great part of diallage rocks and serpentine, and of an amygdaloid with calcareous kernels, and a base of serpentine.

In certain parts of the Morea, the age of these volcanic rocks is established by the following proofs: first, the lithographic limestones (see Vol. I. p. 413.) of the Cretaceous era are cut through by trap, and then a conglomerate occurs, at Nauplia and other places, containing in its calcareous cement many well-known fossils of the chalk and green-sand, together with pebbles formed of rolled pieces of the same ophiolite, which appear in the dikes above alluded to.

It was before stated that strata occur at Tercis, near Dax, in the department of the Landes, in the south of France, containing the fossils of the

Chalk. These cretaceous strata are in great part concealed by unconformable tertiary formations. In one section in this district I observed vertical cretaceous beds, alternating with thin conformable

Fig. 408. Adour R. Luy R. Puy Arzet.

Chalk and volcanic tuff in the environs of Dax.

E. Inclined beds of chalk and conformable volcanic tuff.
a. b. c. d. Gravel, sand, and tertiary strata.

layers of volcanic tuff. Such tuffs were probably the product of submarine eruptions in the cretaceous sea.

The traps of this country and of the neighbouring Pyrenees are generally ophitic, and many French geologists conceive them to be newer than the Cretaceous period, and therefore tertiary; but I know of no sections which demonstrate this point. M. Charpentier has argued that the ophites of the Pyrenees were more modern than all the secondary strata of that chain, because in the conglomerates constituting the upper part of the cretaceous series on the flanks of the Pyrenees, no rolled pebbles of ophite have been found.* But this negative fact may be explained by supposing that, in the cretaceous sea, which occupied

* Charpentier, Essai Geog. sur les Pyrénées, p. 524.

the space where the Pyrenees now stand, the ophitic eruptions were submarine, and never formed islands or shoals exposed to denudation.

The age of the trap of Antrim in Ireland, before described, as altering the chalk by its dikes (p. 220.), is uncertain. It is newer than the chalk of that region, which it cuts through and overflows; and, perhaps, it belongs to some one of the tertiary periods. As wood-coal and coniferous fossil trees have been found associated with it on the eastern shores of Lough Neagh, these plants may hereafter throw light on this chronological question.*

Period of Oolite and Lias.—Although the green and serpentinous trap rocks of the Morea belong chiefly to the Cretaceous era, as before mentioned, yet it seems that some eruptions of similar rocks began during the Oolitic period†; and it is probable, that a large part of the trappean masses, called ophiolites in the Apennines, and associated with the limestone of that chain, are of corresponding age.

Whether part of the volcanic rocks of the Hebrides, in our own country, originated contemporaneously with the Lias and Oolite which they traverse and overlie, remains to be ascertained.

* Dr. Berger, Geol. Trans., First Series, vol. iii. p. 188.
† Boblaye and Virlet, Morea, p. 23.

Trap of the New Red sandstone period. — In the southern part of Devonshire, trappean rocks are associated with New Red sandstone, and, according to Mr. De la Beche, have not been intruded subsequently into the sandstone, but were produced by contemporaneous volcanic action. Some beds of grit, mingled with ordinary red marl, resemble sands ejected from a crater; and in the stratified conglomerates occurring near Tiverton are many angular fragments of trap porphyry, some of them one or two tons in weight, intermingled with pebbles of other rocks. These angular fragments were probably thrown out from volcanic vents, and fell upon sedimentary matter then in the course of deposition.*

Carboniferous period. — Two classes of contemporaneous trap rocks have been ascertained by Dr. Fleming to occur in the coal-field of the Forth in Scotland. The newest of these, connected with the higher series of coal-measures, is well exhibited along the shores of the Forth, in Fifeshire, where they consist of basalt with olivine, amygdaloid, greenstone, wacké, and tuff. They appear to have been erupted while the sedimentary strata were in a horizontal position, and to have suffered the same dislocations which those strata have subsequently undergone. In the volcanic tuffs of

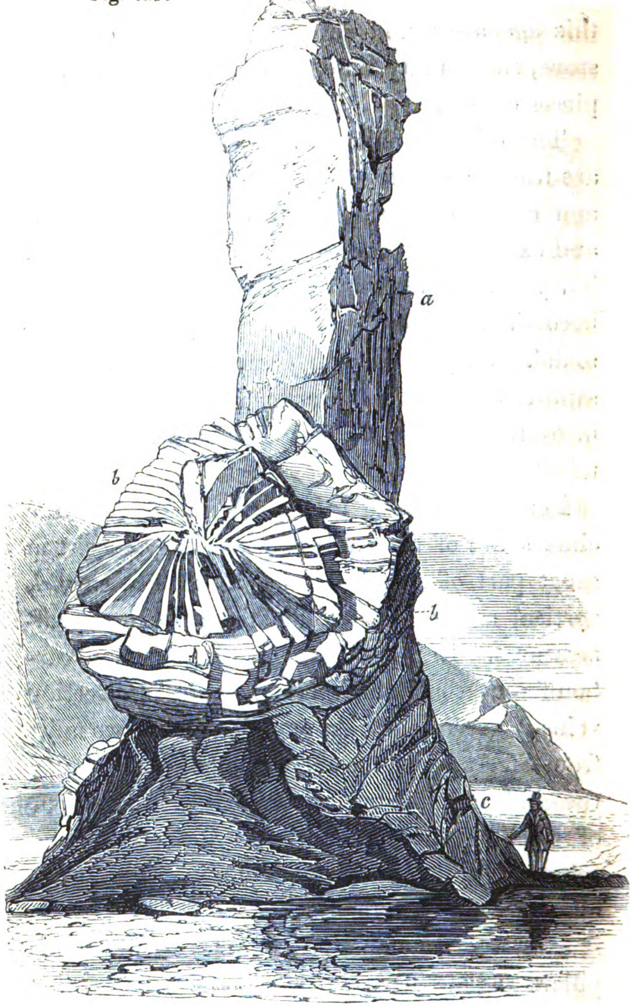
* De la Beche, Geol. Proceedings, No. 41. p. 196.

this age are found not only fragments of limestone, shale, flinty slate, and sandstone, but also pieces of coal.

The other or older class of carboniferous traps are traced along the south margin of Stratheden, and constitute a ridge parallel with the Ochils, and extending from Stirling to near St. Andrews. They consist almost exclusively of greenstone, becoming, in a few instances, earthy and amygdaloidal. They are regularly interstratified with the sandstone, shale, and ironstone of the lower Coal-measures, and, on the East Lomond, with Mountain Limestone.

I examined these trap rocks in 1838, in the cliffs south of St. Andrews where they consist in great part of stratified tuffs, which are curved, vertical and contorted, like the associated coal-measures. In the tuff I found fragments of carboniferous shale and limestone, and intersecting veins of greenstone. At one spot, about two miles from St. Andrews, the encroachment of the sea on the cliffs has isolated several masses of trap, one of which (Fig. 409.) is aptly called the "rock and spindle," for it consists of a pinnacle of tuff, which may be compared to a distaff, and near the base is a mass of columnar greenstone, in which the pillars radiate from a centre, and appear at a distance like the spokes of a wheel. The largest diameter of this wheel is about twelve feet, and

Fig. 409.



Rock and Spindle, St. Andrews.

a. **Unstratified tuff.** *b.* **Columnar greenstone.**

c. **Stratified tuff.**

the polygonal terminations of the columns are seen round the circumference (or tire, as it were,

Fig. 410.

of the wheel), as in the accompanying figure. I conceive this mass to be the extremity of a string or vein of greenstone, which penetrated the tuff. The prisms point in every direction, because they were surrounded on all sides by cooling surfaces, to which they always arrange themselves at right angles, as before explained p. 228.

A trap dike was pointed out to me by Dr. Fleming, in the parish of Flisk, in the northern part of Fifeshire, which cuts through the grey sandstone and shale, forming the lowest part of the Old Red Sandstone. It may be traced for many miles, passing through the amygdaloidal and other traps of the hill called Normans Law. In its course it affords a good exemplification of the passage from the trappean into the plutonic, or highly crystalline texture. Professor Gustavus Rose, to whom I submitted specimens of this dike, finds the rock which he calls dolerite, to consist of greenish black augite and Labrador felspar, the latter being the most abundant ingredient. A small quantity of magnetic iron, perhaps titaniferous, is also present. The result of this analysis is interesting, because both the

ancient and modern lavas of Etna consist in like manner of augite, Labradorite, and titaniferous iron.

Trap of the Old Red sandstone period. — By referring to the section explanatory of the structure of Forfarshire, already given (Vol. I. p. 103.), the reader will perceive that beds of conglomerate, No. 3., occur in the middle of the Old Red sandstone system, 1, 2, 3, 4. The pebbles in these conglomerates are sometimes composed of granitic and quartz rocks, sometimes exclusively of different varieties of trap, which, although purposely omitted in the above section, are often found, either intruding themselves in amorphous masses and dikes into the older fossiliferous tilestones, No. 4., or alternating with them in conformable beds. All the different divisions of the red sandstone, 1, 2, 3, 4, are occasionally intersected by dikes, but they are very rare in Nos. 1. and 2., the upper members of the group consisting of red shale and red sandstone. These phenomena, which occur at the foot of the Grampians, are repeated in the Sidlaw Hills; and it appears that in this part of Scotland volcanic eruptions were most frequent in the earlier part of the Old Red sandstone period.

The trap rocks alluded to consist chiefly of felspathic porphyry and amygdaloid, the kernels of the latter being sometimes calcareous, often calcedonic, and forming beautiful agates. We

meet also with claystone, clinkstone, greenstone, compact felspar, and tuff. Some of these rocks flowed as lavas over the bottom of the sea, and enveloped quartz pebbles which were lying there, so as to form conglomerates with a base of greenstone, as is seen in Lumley Den, in the Sidlaw Hills. On either side of the axis of this chain of hills (see section, Vol. I. p. 103.), the beds of massive trap, and the tuffs composed of volcanic sand and ashes, dip regularly to the south-east or north-west, conformably with the shales and sandstones.

Dr. Fleming has observed similar trap rocks in the old red sandstone of northern Fifeshire, where they are covered immediately by the yellow sandstone which occurs at the base of the Mountain Limestone and Coal-measures, and may be considered as the upper member of the Old Red system.

Silurian period. — It appears from the investigations of Mr. Murchison in Shropshire, that when the lower Silurian strata of that county were accumulating, there were frequent volcanic eruptions beneath the sea; and the ashes and scoriæ then ejected gave rise to a peculiar kind of tufaceous sandstone or grit, dissimilar to the other rocks of the Silurian series, and only observable in places where syenitic and other trap rocks protrude. These tuffs occur on the flanks of the Wrekin and

Caer Caradoc, and contain Silurian fossils, such as casts of encrinites, trilobites, and mollusca. Although fossiliferous, the stone resembles a sandy claystone of the trap family. *

Thin layers of trap, only a few inches thick, alternate, in some parts of Shropshire and Montgomeryshire, with sedimentary strata of the lower Silurian system. This trap consists of slaty porphyry and granular felspar rock, the beds being traversed by joints like those in the associated sandstone, limestone, and shale, and having the same strike and dip. †

In Radnorshire, there is an example of twelve bands of stratified trap alternating with Silurian schists and flagstones in a thickness of 350 feet. The bedded traps consist of felspar-porphyry, clinkstone, and other varieties; and the interposed Llandeilo flags are of sandstone and shale, with trilobites and graptolites. ‡

Cambrian volcanic rocks. — In Pembrokeshire stratified greenstone, felspar-rock, and a breccia containing fragments of trap, alternate conformably in thick parallel masses with regularly stratified sandstone and schist of the *upper Cambrian* system. These trappean masses, says Mr. Murchison, must have been evolved at intervals from volcanic fissures at the bottom of the sea, when

* Murchison, Silurian System, &c. p. 230.
† Ibid., p. 272. ‡ Ibid., p. 325.

the sand, pebbles, and mud, now forming the accompanying sedimentary rocks, were deposited.*

Professor Sedgwick, in his account of the geology of Cumberland, has described various trap-rocks which accompany the green slates of the Cambrian system, beneath a limestone containing organic remains. Different felspathic and porphyritic rocks and greenstones occur, not only in dikes, but in conformable beds; and there is occasionally a passage from these igneous rocks to some of the green quartzose slates. Professor Sedgwick supposes these porphyries to have originated contemporaneously with the stratified chloritic slates, the materials of the slates having been supplied, in part at least, by submarine eruptions oftentimes repeated. †

* Murchison, Silurian System, &c., p. 404.
† Geol. Trans., Second Series, vol. iv. p. 55.

CHAPTER XXXII.

PLUTONIC ROCKS — GRANITE.

General aspect of granite — Decomposing into spherical masses — Rude columnar structure — Analogy and difference of volcanic and plutonic formations — Minerals in granite, and their arrangement—Graphic and porphyritic granite — Occasional minerals — Syenite — Syenitic, talcose, and schorly granites — Eurite — Passage of granite into trap — Examples near Christiania and in Aberdeenshire — Analogy in composition of trachyte and granite — Granite veins in Glen Tilt, Cornwall, the Valorsine, and other countries — Different composition of veins from main body of granite — Metalliferous veins in strata near their junction with granite — Apparent isolation of nodules of granite — Quartz veins — Whether plutonic rocks are ever overlying — Their exposure at the surface due to denudation.

The plutonic rocks may be treated of next in order, as they are most nearly allied to the volcanic class already considered. I have described, in the first chapter, these plutonic rocks as the unstratified division of the crystalline or hypogene formations, and have endeavoured to point out in the Frontispiece, at D, the position which they may occupy, when first formed, relatively to the volcanic formations, B.

It was stated that they differ from the latter, not only by their more crystalline texture, but also by

the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of pores or cellular cavities to which the expansion of the entangled gases give rise in ordinary lava. From these and other peculiarities it has been inferred, that the granites have been formed at great depths in the earth, and have cooled and crystallized slowly under enormous pressure where the contained gases could not expand. The volcanic rocks, on the contrary, although they also have risen up from below, have cooled from a melted state more rapidly upon or near the surface. From this hypothesis of the great depth at which the granites originated, has been derived the name of "Plutonic rocks." The beginner will easily conceive that the influence of subterranean heat may extend downwards from the crater of every active volcano to a great depth below, perhaps several miles or leagues (see Frontispiece), and the effects which are produced deep in the bowels of the earth may, or rather must be distinct; so that volcanic and plutonic rocks, each different in texture, and sometimes even in composition, may originate simultaneously, the one at the surface, the other far beneath it.

By some writers, all the rocks now under consideration have been comprehended under the name of granite, which is, then, understood to em-

brace a large family of crystalline and compound rocks, usually found underlying all other formations; whereas we have seen that trap very commonly overlies strata of different ages. Granite often preserves a very uniform character throughout a wide range of territory, forming hills of a peculiar rounded form, usually clad with a scanty vegetation. The surface of the rock is for the most part in a crumbling state, and the hills are often surmounted by piles of stones like the remains of a stratified mass, as in the annexed figure, and sometimes like heaps of boulders, for

Fig. 411.

Mass of granite near the Sharp Tor, Cornwall.

which they have been mistaken. The exterior of these stones, originally quadrangular, acquires a rounded form by the action of air and water, for the edges and angles waste away more rapidly than the sides. A similar spherical structure has already been described as characteristic of basalt, and other volcanic formations, and it must be referred to analogous causes, as yet but imperfectly understood.

Although it is the general peculiarity of granite to assume no definite shapes, it is nevertheless occasionally subdivided by fissures, so as to assume a cuboidal, and even a columnar, structure. Examples of these appearances may be seen near the Land's End, in Cornwall. (See figure.)

Fig. 412.

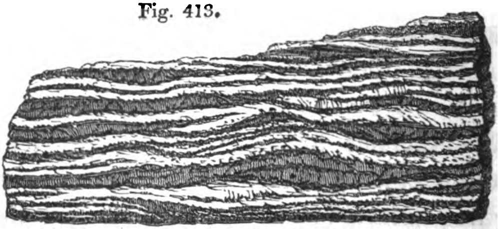
Granite having a cuboidal and rude columnar structure, Land's End, Cornwall.

The plutonic formations also agree with the volcanic, in having veins or ramifications proceeding from central masses into the adjoining rocks, and causing alterations in these last, which will be presently described. They also resemble trap in

containing no organic remains; but they differ in being more uniform in texture, whole mountain masses of indefinite extent appearing to have originated under conditions precisely similar. But they differ in never being scoriaceous or amygdaloidal, in never forming a porphyry with an uncrystalline base, and never alternating with tuffs. Nor do they form conglomerates, although there is sometimes an insensible passage from a fine to a coarse-grained granite, and occasionally patches of a fine texture are imbedded in a coarser variety.

Felspar, quartz, and mica are usually considered as the minerals essential to granite, the felspar being most abundant in quantity, and the proportion of quartz exceeding that of mica. These minerals are united in what is termed a confused crystallization; that is to say, there is no regular arrangement of the crystals in granite, as in gneiss (see Fig. 413.), except in the variety

Fig. 413.



Gneiss. (See description, p. 380.)

termed graphic granite, which occurs mostly in

granitic veins. This variety is a compound of felspar and quartz, so arranged as to produce an imperfect laminar structure. The crystals of felspar

Fig. 414.

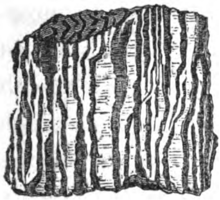
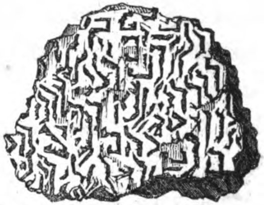


Fig. 415.



Graphic granite.

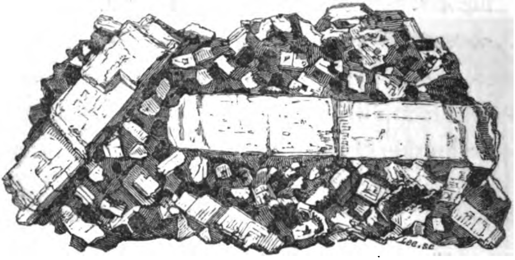
Fig. 414. Section parallel to the laminæ.
Fig. 415. Section transverse to the laminæ.

appear to have been first formed, leaving between them the space now occupied by the darker-coloured quartz. This mineral, when a section is made at right angles to the alternate plates of felspar and quartz, presents broken lines, which have been compared to Hebrew characters.

Porphyritic granite. — This name has been sometimes given to that variety in which large crystals of felspar, sometimes more than an inch in length, are scattered through an ordinary base of granite. An example of this texture may be seen in the granite of the Land's End, in Cornwall. (Fig. 416.) The two larger prismatic crystals in this drawing represent felspar, smaller crystals of which are also seen, similar in form, scattered through the base. In this base also appear black specks of mica, the crystals of which have a more

or less perfect hexagonal outline. The remainder of the mass is quartz, the translucency of which is

Fig. 416.



Porphyritic granite. Land's End, Cornwall.

strongly contrasted to the opaqueness of the white felspar and black mica. But neither the transparency of the quartz, nor the silvery lustre of the mica, can be expressed in the engraving.

The uniform mineral character of large masses of granite seems to indicate that large quantities of the component elements were thoroughly mixed up together, and then crystallized under precisely similar conditions. There are, however, many accidental, or "occasional," minerals as they are termed, which belong to granite. Among these black schorl or tourmaline, actinolite, zircon, garnet, and fluor spar, are not uncommon; but they are too sparingly dispersed to modify the general aspect of the rock. They show, nevertheless, that the ingredients were not everywhere exactly the same; and a still greater variation may be traced

in the ever-varying proportions of the felspar, quartz, and mica.

Syenite. — When hornblende is the substitute for mica, which is very commonly the case, the rock becomes Syenite: so called from the celebrated ancient quarries of Syene in Egypt. It has all the appearance of ordinary granite, except when mineralogically examined in hand specimens, and being fully entitled to rank as a geological member of the same plutonic family as granite. Syenite, however, after maintaining the granitic character throughout extensive regions, is not uncommonly found to lose its quartz, and to pass insensibly into Syenitic greenstone, a rock of the trap family. Werner considered syenite as a binary compound of felspar and hornblende, and regarded quartz as merely one of its occasional minerals.

Syenitic-granite. —The quadruple compound of quartz, felspar, mica, and hornblende, may be so termed. This rock occurs in Scotland and in Guernsey.

Talcose granite, or Protogine of the French, is a mixture of felspar, quartz, and talc. It abounds in the Alps, and in some parts of Cornwall, producing by its decomposition the china clay, more than 12,000 tons of which are annually exported from that country for the potteries.*

* Boase on Primary Geology, p. 16.

Schorl rock, and schorly granite.—The former of these is an aggregate of schorl, or tourmaline, and quartz. When felspar and mica are also present, it may be called schorly granite. This kind of granite is comparatively rare.

Eurite. — A rock in which all the ingredients of granite are blended into a finely granular mass. Crystals of quartz and mica are sometimes scattered through the base of Eurite.

Pegmatite. — A name given by French writers to a variety of granite; a granular mixture of quartz and felspar; frequent in granite veins; passes into graphic granite.

All these granites pass into certain kinds of trap, a circumstance which affords one of many arguments in favour of what is now the prevailing opinion, that the granites are also of igneous origin. The contrast of the most crystalline form of granite, to that of the most common and earthy trap, is undoubtedly great; but each member of the volcanic class is capable of becoming porphyritic, and the base of the porphyry may be more and more crystalline, until the mass passes to the kind of granite most nearly allied in mineral composition.

The minerals which constitute alike the granitic and volcanic rocks, consist, almost exclusively, of seven elements, namely, silica, alumina, magnesia, lime, soda, potash, and iron; and these may some-

times exist in about the same proportions in a porous lava, a compact trap, or a crystalline granite. It may perhaps be found, on farther examination, for on this subject we have yet much to learn, that the presence of these elements in certain proportions is more favourable than in others to their assuming a crystalline or true granitic structure; but it is also ascertained by experiment, that the same materials may, under different circumstances, form very different rocks. The same lava, for example, may be glassy, or scoriaceous, or stony, or porphyritic, according to the more or less rapid rate at which it cools; and some trachytes and syenitic-greenstones may doubtless form granite and syenite, if the crystallization take place slowly.

It would be easy to multiply examples and authorities to prove the gradation of the granitic into the trap rocks. On the western side of the fiord of Christiania, in Norway, there is a large district of trap, chiefly greenstone-porphyry, and syenitic-greenstone, resting on fossiliferous strata. To this, on its southern limit, succeeds a region equally extensive of syenite, the passage from the volcanic to the plutonic rock being so gradual that it is impossible to draw a line of demarcation between them.

"The ordinary granite of Aberdeenshire," says Dr. MacCulloch, "is the usual ternary compound

of quartz, felspar, and mica; but sometimes hornblende is substituted for the mica. But in many places a variety occurs which is composed simply of felspar and hornblende; and in examining more minutely this duplicate compound, it is observed in some places to assume a fine grain, and at length to become undistinguishable from the greenstones of the trap family. It also passes in the same uninterrupted manner into a basalt, and at length into a soft claystone, with a schistose tendency on exposure, in no respect differing from those of the trap islands of the western coast."* The same author mentions, that in Shetland, a granite composed of hornblende, mica, felspar, and quartz, graduates in an equally perfect manner into basalt.†

In Hungary there are varieties of trachyte, which, geologically speaking, are of modern origin, in which crystals, not only of mica, but of quartz, are common, together with felspar and hornblende. It is easy to conceive how such volcanic masses may, at a certain depth from the surface, pass downwards into granite.

I have already hinted at the close analogy in the forms of certain granitic and trappean veins; and it will be found that strata penetrated by plutonic rocks have suffered changes very similar

* Syst. of Geol., vol. i. p. 157. † Ibid., p. 158.

to those exhibited near the contact of volcanic dikes. Thus, in Glen Tilt, in Scotland, alternating strata of limestone and argillaceous schist come in contact with a mass of granite. The contact does not take place as might have been looked for, if the granite had been formed there before the strata were deposited, in which case the section would have appeared as in Fig. 417.; but the union is as represented in Fig. 418., the

Fig. 417.

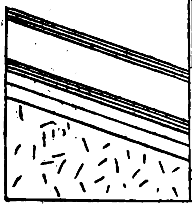
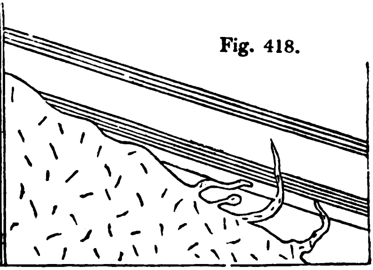


Fig. 418.



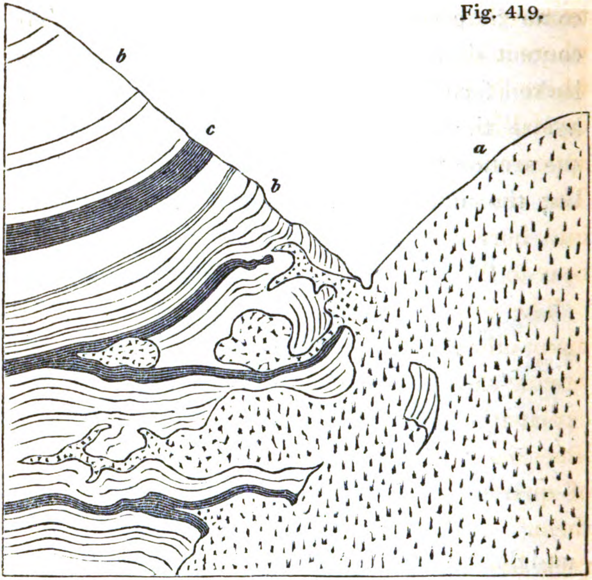
Junction of granite and argillaceous schist in Glen Tilt. (MacCulloch.)*

undulating outline of the granite intersecting different strata, and occasionally intruding itself in tortuous veins into the beds of clay-slate and limestone, from which it differs so remarkably in composition. The limestone is sometimes changed in character by the proximity of the granitic mass or its veins, and acquires a more compact texture, like that of hornstone or chert, with a splintery fracture, effervescing feebly with acids.

* Geol. Trans., First Series, vol. iii. pl. 21.

The annexed diagram (Fig. 419.) represents another junction, in the same district, where the

Fig. 419.



Junction of granite and limestone in Glen Tilt. (MacCulloch.)

a. Granite. *b.* Limestone.
c. Blue argillaceous schist.

granite sends forth so many veins as to reticulate the limestone and schist, the veins diminishing towards their termination to the thickness of a leaf of paper or a thread. In some places fragments of granite appear entangled, as it were, in the limestone, and are not visibly connected with any larger mass; while sometimes, on the other

hand, a lump of the limestone is found in the midst of the granite. The ordinary colour of the limestone of Glen Tilt is lead blue, and its texture large-grained and highly crystalline; but where it approximates to the granite, particularly where it is penetrated by the smaller veins, the crystalline texture disappears, and it assumes an appearance exactly resembling that of hornstone. The associated argillaceous schist often passes into hornblende slate, where it approaches very near to the granite.*

The conversion of the limestone in these and many other instances into a siliceous rock, effervescing slowly with acids, would be difficult of explanation, were it not ascertained that such limestones are always impure, containing grains of quartz, mica, or felspar disseminated through them. The elements of these minerals, when the rock has been subjected to great heat, may have been fused, and so spread more uniformly through the whole mass.

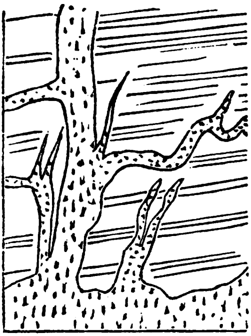
In the plutonic, as in the volcanic rocks, there is every gradation from a tortuous vein to the most regular form of a dike, such as intersect the tuffs and lavas of Vesuvius and Etna. Dikes of granite may be seen, among other places, on the southern flank of Mount Battock, one of the

* MacCulloch, Geol. Trans., vol. iii. p. 259.

Grampians, the opposite walls sometimes preserving an exact parallelism for a considerable distance.

As a general rule, however, granite veins in all quarters of the globe are more sinuous in their course than those of trap. They present similar shapes at the most northern point of Scotland, and the southernmost extremity of Africa, as the annexed drawings will show.

Fig. 420.



*Granite veins traversing clay slate, Table Mountain, Cape of Good Hope.**

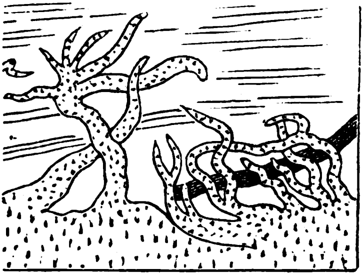
It is not uncommon for one set of granite veins to intersect another; and sometimes there are three sets, as in the environs of Heidelberg, where the granite on the banks of the river Necker is seen to consist of three varieties, differing in colour, grain, and various peculiarities of mineral composition. One of these, which is evidently the second in age, is seen to cut through an older granite; and another, still newer, traverses both the second and the first.

In Shetland there are two kinds of granite. One of them, composed of hornblende, mica, fel-

* Capt. B. Hall, Trans. Roy. Soc. Edin., vol. vii.

spar, and quartz, is of a dark colour, and is seen underlying gneiss. The other is a red granite, which penetrates the dark variety everywhere in veins.*

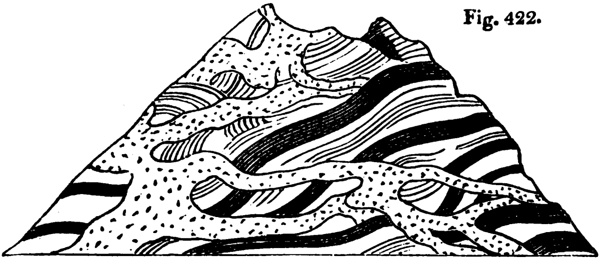
Fig. 421.



Granite veins traversing gneiss, Cape Wrath. (MacCulloch.) †

The accompanying sketches will explain the manner in which granite veins often ramify and cut each other. (Figs. 421. and 422.) They re-

Fig. 422.



Granite veins traversing gneiss at Cape Wrath, in Scotland. (MacCulloch.)

present the manner in which the gneiss at Cape Wrath, in Sutherlandshire, is intersected by veins.

* MacCulloch, Syst. of Geol., vol. i. p. 58.
† Western Islands, pl. 31.

Their light colour, strongly contrasted with that of the hornblende-schist, here associated with the gneiss, renders them very conspicuous.

Granite very generally assumes a finer grain, and undergoes a change in mineral composition, in the veins which it sends into contiguous rocks. Thus, according to Professor Sedgwick, the main body of the Cornish granite is an aggregate of mica, quartz, and felspar; but the veins are sometimes without mica, being a granular aggregate of quartz and felspar. In other varieties quartz prevails to the almost entire exclusion both of felspar and mica; in others, the mica and quartz both disappear, and the vein is simply composed of white granular felspar.*

Fig. 423. is a sketch of a group of granite veins

Fig. 423.

Granite veins passing through hornblende slate, Carnsilver Cove, Cornwall.

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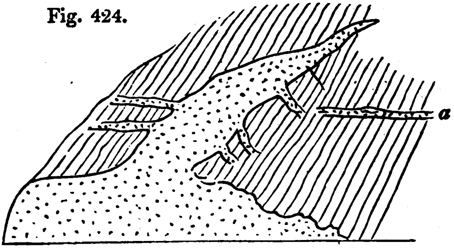
* On Geol. of Cornwall, Camb. Trans. vol. i. p. 124.

in Cornwall, given by Messrs. Von Oeynhausen and Von Dechen.* The main body of the granite here is of a porphyritic appearance, with large crystals of felspar; but in the veins it is fine-grained, and without these large crystals. The general height of the veins is from sixteen to twenty feet, but some are much higher.

In the Valorsine, a valley not far from Mont Blanc, in Switzerland, an ordinary granite, consisting of felspar, quartz, and mica, sends forth veins into a talcose gneiss (or stratified protogine), and in some places lateral ramifications are thrown off from the principal veins at right angles (see Fig. 424.), the veins, especially the minuter ones, being finer grained than the granite in mass.

Fig. 424.



Veins of granite in talcose gneiss. (L. A. Necker.)

It is here remarked, that the schist and granite, as they approach, seem to exercise a reciprocal

* Phil. Mag. and Annals, No. 27. New Series, March, 1829.

influence on each other, for both undergo a modification of mineral character. The granite, still remaining unstratified, becomes charged with green particles; and the talcose gneiss assumes a granitiform structure, without losing its stratification.*

Professor Keilhau drew my attention to several localities in the country near Christiania, where the mineral character of gneiss appears to have been affected by a granite of much newer origin, for some distance from the point of contact. The gneiss, without losing its laminated structure, seems to have become charged with a larger quantity of felspar, and that of a redder colour, than the felspar usually belonging to the gneiss of Norway.

Granite, syenite, and those porphyries which have a granitiform structure, in short all plutonic rocks, are frequently observed to contain metals, at or near their junction with stratified formations. On the other hand, the veins which traverse stratified rocks are, as a general law, more metalliferous near such junctions than in other positions. Hence it has been inferred that these metals may have been spread in a gaseous form through the fused mass, and that the contact of another rock, in a different state of temperature, or sometimes

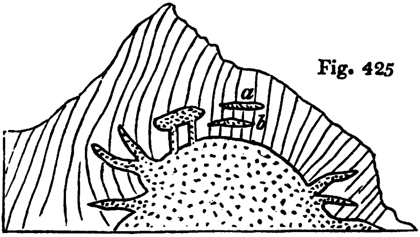
* Necker, sur la Val. de Valorsine, Mém. de la Soc. de Phys. de Génève, 1828.—I visited, in 1832, the spot referred to in Fig. 424.

the existence of rents in other rocks in the vicinity, may have caused the sublimation of the metals.*

There are many instances, as at Markerud, near Christiania, in Norway, where the strike of the beds has not been deranged throughout a large area by the intrusion of granite, both in large masses and in veins. This fact is considered by some geologists to militate against the theory of the forcible injection of granite in a fluid state. But it may be stated in reply, that ramifying dikes of trap, which almost all now admit to have been once fluid, pass through the same fossiliferous strata, near Christiania, without deranging their strike or dip.†

The real or apparent isolation of large or small

Fig. 425



General view of junction of granite and schist of the Valorsine.
(L. A. Necker.)

masses of granite detached from the main body, as at *a b*, Fig. 425., and above, Fig. 419., and *a*,

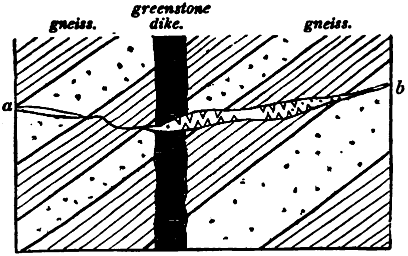
* Necker, Proceedings of Geol. Soc., No. 26. p. 392.
† See Keilhau's Gæa Norvegica; Christiania, 1838.

Fig. 424., has been thought by some writers to be irreconcilable with the doctrine usually taught respecting veins; but many of them may, in fact, be sections of root-shaped prolongations of granite; while, in other cases, they may in reality, be detached portions of rock having the plutonic structure. For there may have been spots in the midst of the invaded strata, in which there was an assemblage of materials more fusible than the rest, or more fitted to combine readily into some form of granite.

Veins of pure quartz are often found in granite, as in many stratified rocks, but they are not traceable, like veins of granite or trap, to large bodies of rock of similar composition. They appear to have been cracks, into which siliceous matter was infiltered. Such segregation, as it is called, can sometimes be shown to have clearly taken place long subsequently to the original consolidation of the containing rock. Thus, for example, in the gneiss of Tronstad Strand, near Drammen, in Norway, the annexed section is seen on the beach. It appears that the alternating strata of whitish granitiform gneiss, and black hornblende-schist, were first cut through by a greenstone dike, about 2½ feet wide; then the crack *a b* passed through all these rocks, and was filled up with quartz. The opposite walls of the vein are in some parts incrusted with transparent crystals of quartz, the

middle of the vein being filled up with common opaque white quartz.

Fig. 426.

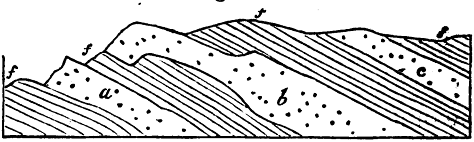


a. b. Quartz vein passing through gneiss and greenstone, Tronstad Strand, near Christiania.

We have seen that the volcanic formations have been called overlying, because they not only penetrate others, but spread over them. Mr. Necker has proposed to call the granites the underlying igneous rocks, and the distinction here indicated is highly characteristic. It was indeed supposed by Von Buch, at the commencement of his geological career, that the granite of Christiania, in Norway, was sometimes intercalated in mountain masses between the transition strata of that country, overlying fossiliferous shale and limestone. But although the granite sends veins into these fossiliferous rocks, and is decidedly posterior in origin, the opinion expressed of its actual superposition in mass has been disproved by Professor Keilhau, some of whose observations respecting localities referred to by Von Buch, I had oppor-

tunities in 1837 of verifying. There are, however, on a smaller scale, certain beds of euritic porphyry, some a few feet, others many yards in thickness, which pass into granite, and deserve perhaps to be classed as plutonic rather than trappean rocks, which may truly be described as interposed conformably between fossiliferous strata, as the porphyries (*a c*, Fig. 427.), which divide the bituminous shales and argillaceous limestones, *f f*. But some of these same porphyries are partially

Fig. 427.



Euritic porphyry alternating with fossiliferous transition strata, near Christiania.

unconformable, as *b*, and may lead us to suspect that the others also, notwithstanding their appearance of interstratification, have been forcibly injected. Some of the porphyritic rocks above mentioned are highly quartzose, others very felspathic. In proportion as the masses are more voluminous, they become more granitic in their texture, less conformable, and even begin to send forth veins into contiguous strata. In a word, we have here a beautiful illustration of the intermediate gradations between volcanic and plutonic rocks, not only in their mineralogical composition

and structure, but also in their relations of position to associated formations. If the term overlying can in this instance be applied to a plutonic rock, it is only in proportion as that rock begins to acquire a trappean aspect.

It has been already hinted that the heat, which in every active volcano extends downwards to indefinite depths, must produce simultaneously very different effects near the surface, and far below it; and we cannot suppose that rocks resulting from the crystallizing of fused matter under a pressure of several miles of the earth's crust can resemble those formed at or near the surface. Hence the production at great depths of a class of rocks analogous to the volcanic, and yet differing in many particulars, might almost have been predicted, even had we no plutonic formations to account for. How well these agree, both in their positive and negative characters, with the theory of their deep subterranean origin, the student will be able to judge by considering the descriptions already given.

It has, however, been objected, that if the granitic and volcanic rocks were simply different parts of one great series, we ought to find in mountain chains volcanic dikes passing upwards into lava, and downwards into granite. But we may answer, that our vertical sections are usually of small extent; and if we find in certain places

a transition from trap to porous lava, and in others a passage from granite to trap, it is as much as could be expected of this evidence.

The prodigious extent of denudation which has been already demonstrated to have occurred at former periods, will reconcile the student to the belief that crystalline rocks of high antiquity, although deep in the earth's crust when originally formed, may have become uncovered and exposed at the surface. Their actual elevation above the sea may be referred to the same causes to which we have attributed the upheaval of marine strata, even to the summits of some mountain chains. But to these and other topics, I shall revert when speaking, in the next chapter, of the relative ages of different masses of granite.

CHAPTER XXXIII.

ON THE DIFFERENT AGES OF THE PLUTONIC ROCKS.

Difficulty in ascertaining the precise age of a plutonic rock — Test of age by relative position — Test by intrusion and alteration — Test by mineral composition — Test by included fragments — Recent and Pliocene plutonic rocks, why invisible — Tertiary plutonic rocks in the Andes — Granite altering Cretaceous rocks — Granite altering Lias in the Alps and in Sky — Granite of Dartmoor altering Carboniferous strata — Granite of the Old Red sandstone period — Syenite altering Silurian strata in Norway — Blending of the same with gneiss — Most ancient plutonic rocks — Granite protruded in a solid form — On the probable age of the granites of Arran, in Scotland.

When we adopt the igneous theory of granite, as explained in the last chapter, and believe that different plutonic rocks have originated at successive periods beneath the surface of the planet, we must be prepared to encounter greater difficulty in ascertaining the precise age of such rocks, than in the case of volcanic and fossiliferous formations. We must bear in mind, that the evidence of the age of each contemporaneous volcanic rock was derived, either from lavas poured out upon the ancient surface, whether in the sea or in the atmosphere, or from tuffs and conglomerates, also deposited at

the surface, and either containing organic remains themselves, or intercalated between strata containing fossils. But all these tests fail when we endeavour to fix the chronology of a rock, which has crystallized from a state of fusion in the bowels of the earth. In that case, we are reduced to the following tests; 1st, relative position; 2dly, intrusion, and alteration of the rocks in contact; 3dly, mineral characters; 4thly, included fragments.

Test of age by relative position. — Unaltered fossiliferous strata of every age are met with reposing immediately on plutonic rocks; as at Christiania, in Norway, where the Newer Pliocene deposits rest on granite; in Auvergne, where the freshwater Eocene strata, and at Heidelberg, on the Rhine, where the New Red sandstone, occupy a similar place. In all these, and similar instances, inferiority in position is connected with the superior antiquity of granite. The crystalline rock was solid before the sedimentary beds were superimposed, and the latter usually contain in them rounded pebbles of the subjacent granite.

Test by intrusion and alteration. — But when plutonic rocks send veins into strata, and alter them near the point of contact, in the manner before described (p. 335.), it is clear that, like intrusive traps, they are newer than the strata which they invade and alter. Examples of the application of this test will be given in the sequel.

Test by mineral composition. — Notwithstanding a general uniformity in the aspect of plutonic rocks, we have seen in the last chapter that there are many varieties, such as Syenite, Talcose granite, and others. One of these varieties is sometimes found exclusively prevailing throughout an extensive region, where it preserves a homogeneous character; so that having ascertained its relative age in one place, we can easily recognize its identity in others, and thus determine from a single section the chronological relations of large mountain masses. Having observed, for example, that the syenitic granite of Norway, in which the mineral called zircon abounds, has altered the Silurian strata wherever it is in contact, we do not hesitate to refer all masses of the same zircon-syenite in the south of Norway to the same era. (See p. 402.)

Some have imagined that the age of different granites might, to a great extent, be determined by their mineral characters alone; syenite, for instance, or granite with hornblende, being more modern than common or micaceous granite. But modern investigations have proved these generalizations to have been premature. The syenitic granite of Norway already alluded to may be of the same age as the Silurian strata, which it traverses and alters, or may belong to the Old Red sandstone period; whereas the granite of Dartmoor,

although consisting of mica, quartz, and felspar, is newer than the Coal. (See p. 364.)

Test by included fragments.—This criterion can rarely be of much importance, because the fragments involved in granite are usually so much altered, that they cannot be referred with certainty to the rocks whence they were derived. In the White Mountains, in North America, according to Professor Hubbard, a granite vein traversing granite, contains fragments of slate and trap, which must have fallen into the fissure when the fused materials of the vein were injected from below*, and thus the granite is shown to be newer than certain superficial slaty and trappean formations.

Recent and Pliocene plutonic rocks, why invisible.—The explanation already given in the 28th and in the last chapter of the probable relation of the plutonic to the volcanic formations, will naturally lead the reader to infer, that rocks of the one class can never be produced at or near the surface without some members of the other being formed below simultaneously, or soon afterwards. It is not uncommon for lava streams to require more than ten years to cool in the open air; and where they are of great depth, a much longer period. The melted matter poured from Jorullo, in Mexico, in the year 1759, which accumulated in some places to

* Silliman's Journ., No. 69. p. 123.

the height of 550 feet, was found to retain a high temperature half a century after the eruption.* We may conceive, therefore, that great masses of subterranean lava may remain in a red-hot or incandescent state in the volcanic foci for immense periods, and the process of refrigeration may be extremely gradual. Sometimes, indeed, this process may be retarded for an indefinite period, by the accession of fresh supplies of heat; for we find that the lava in the crater of Stromboli, one of the Lipari islands, has been in a state of constant ebullition for the last two thousand years; and we may suppose this fluid mass to communicate with some caldron or reservoir of fused matter below. In the Isle of Bourbon, also, where there has been an emission of lava once in every two years for a long period, the lava below can scarcely fail to have been permanently in a state of liquefaction. If then it be a reasonable conjecture, that about 2000 volcanic eruptions occur in the course of every century, either above the waters of the sea or beneath them†, it will follow, that the quantity of plutonic rock generated, or in progress during the Recent epoch, must already have been considerable.

But as the plutonic rocks originate at some

* See "Principles," Index, "Jorullo."

† Ibid, Index, "Volcanic Eruptions."

depth in the earth's crust, they can only be rendered accessible to human observation, by subsequent upheaval and denudation. Between the period when a plutonic rock crystallizes in the subterranean regions, and the era of its protrusion at any single point of the surface, one or two geological periods must usually intervene. Hence, we must not expect to find the Recent or Newer Pliocene granites laid open to view, unless we are prepared to assume that sufficient time has elapsed since the commencement of the Newer Pliocene period for great upheaval and denudation. A plutonic rock, therefore, must, in general, be of considerable antiquity relatively to the fossiliferous and volcanic formations, before it becomes extensively visible. As we know that the upheaval of land has been sometimes accompanied in South America by volcanic eruptions and the emission of lava, we may conceive the more ancient plutonic rocks to be forced upwards to the surface by the newer rocks of the same class formed successively below, — subterposition in the plutonic, like superposition in the sedimentary rocks, being usually characteristic of a newer origin.

In the accompanying diagram, Fig. 428., an attempt is made to show the inverted order in which sedimentary and plutonic formations may occur in the earth's crust.

Fig. 428.

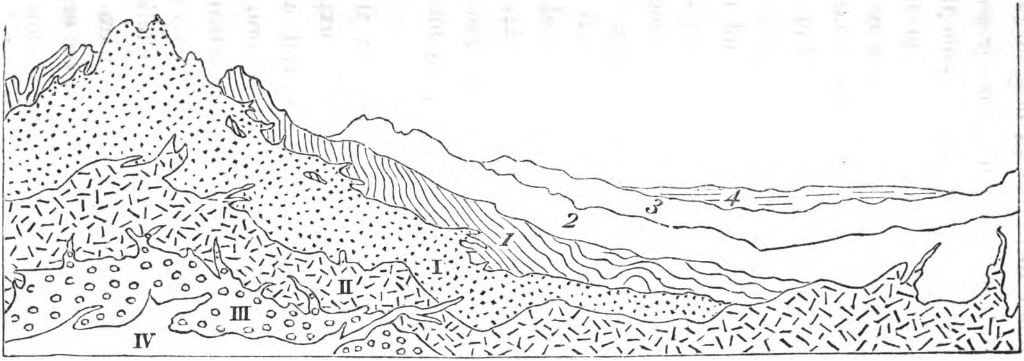


Diagram showing the relative position which the plutonic and sedimentary formations of different ages may occupy.

I. Primary plutonic.
II. Secondary plutonic.
III. Tertiary plutonic.
IV. Recent plutonic.

4. Recent strata.
3. Tertiary strata.
2. Secondary strata.
1. Primary fossiliferous strata.

The metamorphic rocks are not indicated in this diagram, but the student may learn from the Frontispiece what place they would occupy if portions of the strata Nos. 1. and 2., invaded by granite, had become metamorphic.

The oldest plutonic rock, No. I., has been upheaved at successive periods until it has become exposed to view in a mountain-chain. This protrusion of No. I. has been caused by the igneous agency which produced the new plutonic rocks Nos. II. III. and IV. Part of the primary fossiliferous strata, No. 1., have also been raised to the surface by the same gradual process. It will be observed that the Recent *strata* No. 4., and the Recent *granite* or plutonic rock No. IV., are the most remote from each other in position, although of contemporaneous date. According to this hypothesis, the convulsions of many periods will be required before *Recent* granite will be upraised so as to form the highest ridges and central axes of mountain-chains. During that time the *Recent* strata No. 4. might be covered by a great many newer sedimentary formations.

Tertiary plutonic rocks. — We have seen that great upheaving movements have been experienced in the region of the Andes, during the Post-Pliocene period. In some part, therefore, of this chain, if any where, we may hope to discover tertiary plutonic rocks laid open to view. What we already know of the structure of the Chilian Andes seems to realize this expectation. In a transverse section, examined by Mr. Darwin, between Valparaiso and Mendoza, the Cordillera was found to consist of two separate and parallel chains,

formed of sedimentary rocks of different ages, the strata in both resting on plutonic rocks, by which they have been altered. In the western or oldest range, called the Peuquenes, are black calcareous clay-slates, rising to the height of nearly 14,000 feet above the sea, in which are shells of the genera *Gryphæa*, *Turritella*, *Terebratula*, and *Ammonite*. These rocks are supposed to be of the age of the central parts of the secondary series of Europe. They are penetrated and altered by dikes and mountain masses of a plutonic rock, which has the texture of ordinary granite, but rarely contains quartz, being a compound of albite and hornblende.

The second or eastern chain consists chiefly of sandstones and conglomerates, of vast thickness, the materials of which are derived from the ruins of the western chain. The pebbles of the conglomerates are, for the most part, rounded fragments of the fossiliferous slates before mentioned. The resemblance of the whole series to certain tertiary deposits on the shores of the Pacific, not only in mineral character, but in the imbedded lignite and silicified wood, leads to the conjecture that they also are tertiary. Yet these strata are not only associated with trap rocks and volcanic tuffs, but are also altered by a granite newer than that of the western chain, and consisting of quartz, felspar, and talc. They are traversed, moreover,

by dikes of the same granite, and by numerous veins of iron, copper, arsenic, silver, and gold; all of which can be traced to the underlying granite.* We have, therefore, strong ground to presume that the plutonic rock, here exposed on a large scale in the Chilian Andes, is of later date than certain tertiary formations.

But the theory adopted in this work of the subterranean origin of the hypogene formations would be untenable, if the supposed fact here alluded to, of the appearance of tertiary granite at the surface, was not a rare exception to the general rule. A considerable lapse of time must intervene between the formation in the nether regions of plutonic and metamorphic rocks, and their emergence at the surface. For a long series of subterranean movements must occur before such rocks can be uplifted into the atmosphere or the ocean; and, before they can be rendered visible to man, some strata which previously covered them must usually have been stripped off by denudation.

We know that in the Bay of Baiæ, in 1538, in Cutch in 1819, and on several occasions in Peru and Chili, since the commencement of the present century, the permanent upheaval or subsidence of land has been accompanied by the

* Darwin, pp. 390. 406.

simultaneous emission of lava at one or more points in the same volcanic region. From these and other examples it may be inferred that the rising or sinking of the earth's crust, operations by which sea is converted into land, and land into sea, are a part only of the consequences of subterranean igneous action. It can scarcely be doubted that this action consists, in a great degree, of the baking, and occasionally the liquefaction, of rocks, causing them to assume, in some cases a larger, in others a smaller, volume than before the application of heat. It consists also in the generation of gases, and their expansion by heat, and the injection of liquid matter into rents formed in superincumbent rocks. The prodigious scale on which these subterranean causes have operated in Sicily since the deposition of the Newer Pliocene strata will be appreciated, when we remember that throughout half the surface of that island such strata are met with, raised to the height of from 50 to that of 2000, and even 3000 feet above the level of the sea. In the same island also the older rocks which are contiguous to these marine tertiary strata must have undergone, within the same period, a similar amount of upheaval.

The like observations may be extended to nearly the whole of Europe, for, since the commencement of the Eocene period, the entire Eu-

ropean area, as I have elsewhere shown*, has, with the exception of a few districts, emerged from the deep to its present altitude, and even those tracts, which were already dry land before the Eocene era, have almost everywhere acquired additional height. A large amount of subsidence has also occurred during the same period, so that the extent of the subterranean spaces which have either become the receptacles of sunken fragments of the earth's crust, or have been rendered capable of supporting other fragments at a much greater height than before, must be so great that they probably equal, if not exceed in volume, the entire continent of Europe. We are entitled, therefore, to ask what amount of change of equivalent importance can be proved to have occurred in the earth's crust within an equal quantity of time anterior to the Eocene epoch? They who contend for the more intense energy of subterranean causes in the remoter eras of the earth's history, may find it more difficult to give an answer to this question than they anticipated.

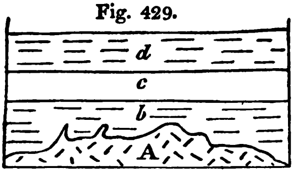
The principal effect of volcanic action in the nether regions, during the tertiary period, seems to have consisted in the upheaval to the surface of

* See Map of Europe and Explanation, in Principles, book i.

hypogene formations of an age anterior to the carboniferous. The repetition of another series of movements, of equal violence, might upraise the plutonic and metamorphic rocks of many secondary periods; and if the same force should still continue to act, the next convulsions might bring up to the day the *tertiary* and *recent* hypogene rocks. In the course of such changes many of the existing sedimentary strata would suffer greatly by denudation, others might assume a metamorphic structure, or become melted down into plutonic and volcanic rocks. Meanwhile the deposition of a vast thickness of new strata would not fail to take place during the upheaval and partial destruction of the older rocks. But I must refer the reader to the last chapter of this volume (see p. 426.) for a fuller explanation of these views.

Cretaceous period.—It will be shown in the next chapter that chalk as well as lias have been altered by granite in the eastern Pyrenees. Whether such granite be cretaceous or tertiary cannot easily be decided. Suppose *b*, *c*, *d*, to be three members of the Cretaceous series, the lowest of which, *b*, has been altered by the granite A, the modifying influence not having extended so far as *c*, or

Fig. 429.



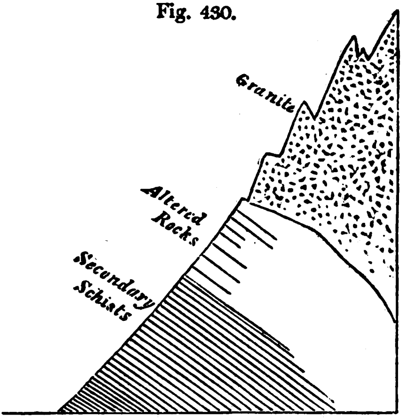
having but slightly affected its lowest beds. Now it can rarely be possible for the geologist to decide whether the beds *d* existed at the time of the intrusion of A, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*.

As some Cretaceous rocks, however, have been raised to the height of more than 9000 feet in the Pyrenees, we must not assume that plutonic formations of the same age may not have been brought up and exposed by denudation, at the height of 2000 or 3000 feet on the flanks of that chain.

Period of Oolite and Lias. — In the department of the Hautes Alpes, in France, near Vizille, M. Elie de Beaumont traced a black argillaceous limestone, charged with belemnites, to within a few yards of a mass of granite. Here the limestone begins to put on a granular texture, but is extremely fine-grained. When nearer the junction it becomes grey, and has a saccharoid structure. In another locality, near Champoleon, a granite composed of quartz, black mica, and rose-coloured felspar, is observed partly to overlie the secondary rocks, producing an alteration which extends for about thirty feet downwards, diminishing in the beds which lie farthest from the granite. (See Fig. 430.) In the altered mass the argillaceous beds are hardened, the limestone is saccharoid, the gritz quartzose, and

in the midst of them is a thin layer of an imperfect granite. It is also an important circumstance,

Fig. 430.



Junction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

that near the point of contact, both the granite and the secondary rocks become metalliferous, and contain nests and small veins of blende, galena, iron, and copper pyrites. The stratified rocks become harder and more crystalline, but the granite, on the contrary, softer and less perfectly crystallized near the junction.*

Although the granite is incumbent in the above section (Fig. 430.), we cannot assume that it overflowed the strata, for the disturbances of the rocks

* Elie de Beaumont, sur les Montagnes de l'Oisans, &c. Mém. de la Soc. d'Hist. Nat. de Paris, tom. v.

are so great in this part of the Alps that they seldom retain the position which they must originally have occupied.

A considerable mass of syenite, in the Isle of Sky, is described by Dr. MacCulloch as intersecting limestsone and shale, which are of the age of the lias.* The limestone, which, at a greater distance from the granite, contains shells, exhibits no traces of them near its junction, where it has been converted into a pure crystalline marble.†

At Predazzo, in the Tyrol, secondary strata, some of which are limestones of the Oolitic period, have been traversed and altered by plutonic rocks, one portion of which is an augitic porphyry, which passes insensibly into granite. The limestone is changed into granular marble, with a band of serpentine at the junction.‡

Carboniferous period.—The granite of Dartmoor, in Devonshire, was formerly supposed to be one of the most ancient of the plutonic rocks, but is now ascertained to be posterior in date to the culm-measures of that county, which, from their position, and as containing true coal-plants,

* See Murchison, Geol. Trans., 2nd series, vol. ii. part ii. pp. 311—321.

† Western Islands, vol. i. p. 330. plate 18. figs. 3, 4.

‡ Von Buch, Annales de Chimie, &c.

are regarded by Professor Sedgwick and Mr. Murchison as members of the true carboniferous series. This granite, like the syenitic granite of Christiania, has broken through the stratified formations without much changing their strike. Hence, on the north-west side of Dartmoor, the successive members of the culm-measures abut against the granite, and become metamorphic as they approach. These strata are also penetrated by granite veins and plutonic dikes, called "elvans."* The granite of Cornwall is probably of the same date, and, therefore, as modern as the Carboniferous strata, if not much newer.

Old Red sandstone period.—The plutonic rocks of the Malvern Hills in Worcestershire, consist of a granitic compound of quartz, felspar, and hornblende, or occasionally of quartz, mica, and felspar, which passes into syenite and greenstone.† This rock has altered the adjacent Silurian strata into well characterized metamorphic schists, principally chloritic and micaceous-schist, with some gneiss, and has dislocated and reversed the position of the beds of the Silurian and Old Red sandstone. There are indications, says Mr. Murchison, of several periods of movement, by which the strata were forced up and folded back, but the

* Proceedings of Geol. Soc., vol. ii. p. 562.
† Mr. L. Horner, Geol. Trans., 1st ser., vol. i. p. 281.

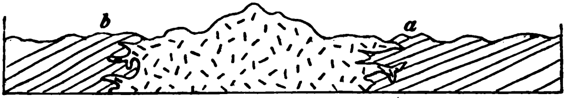
chief outburst was after the accumulation of the Silurian and part of the Old Red System, and anterior to the formation of the coal-beds, which are undisturbed.*

Silurian period. — It has long been known that the granite near Christiania, in Norway, is of newer origin than the Silurian strata of that region. Von Buch first announced, in 1813, the discovery of its posteriority in date to limestones containing orthocerata and trilobites. The proofs consist in the penetration of granite veins into the shale and limestone, and the alteration of the strata, for a considerable distance from the point of contact, both of these veins and the central mass from which they emanate. (See p. 345.) Von Buch supposed that the plutonic rock alternated with the fossiliferous strata, and that large masses of granite were sometimes incumbent upon the strata; but this idea was erroneous, and arose from the fact that the beds of shale and limestone often dip towards the granite up to the point of contact, appearing as if they would pass under it in mass, as at *a*, Fig. 431., and then again on the opposite side of the same mountain, as at *b*, dip away from the same granite. When the junctions, however, are carefully examined, it is found that the plutonic rock intrudes itself in veins, and no

* Silurian System, p. 425.

where covers the fossiliferous strata in large overlying masses, as is so commonly the case with trappean formations.*

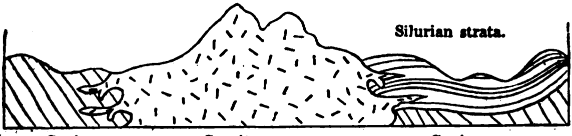
Fig. 431.



Now this granite, which is more modern than the Silurian strata of Norway, also sends veins in the same country into an ancient formation of gneiss; and the relations of the plutonic rock and the gneiss, at their junction, are full of interest when we duly consider the wide difference of epoch which must have separated their origin.

The length of this interval of time is attested by the following facts: — The fossiliferous, or

Fig. 432.



Granite sending veins into Silurian strata and Gneiss, — Christiania, Norway.

transition beds, rest unconformably upon the truncated edges of the gneiss, the inclined strata

* See the Gæa Norvegica and other works of Keilhau, with whom I examined this country.

of which had been disturbed and denuded before the sedimentary beds were superimposed (see Fig. 432.). The signs of denudation are twofold; first, the surface of the gneiss is seen occasionally on the removal of the newer beds, containing organic remains, to be scored and polished; secondly, pebbles of gneiss have been found in some of the transition strata. Between the origin, therefore, of the gneiss and the granite there intervened, first, the period when the strata of gneiss were inclined; secondly, the period when they were denuded; thirdly, the period of the deposition of the transition deposits. Yet the granite produced, after this long interval, is often so intimately blended with the ancient gneiss, at the point of junction, that it is impossible to draw any other than an arbitrary line of separation between them; and where this is not the case, tortuous veins of granite pass freely through gneiss, ending sometimes in threads, as if the older rock had offered no resistance to their passage. It seems necessary, therefore, to conceive that the gneiss was softened and more or less melted when penetrated by the granite. But had such junctions alone been visible, and had we not learnt, from other sections, how long a period elapsed between the consolidation of the gneiss, and the injection of this granite, we might have suspected that the gneiss was scarcely solidified, or had not yet assumed its com-

plete metamorphic character, when invaded by the plutonic rock. From this example we may learn how impossible it is to conjecture whether certain granites in Scotland, and other countries, which send veins into gneiss and other metamorphic rocks, are primary, or whether they may not belong to some secondary or tertiary period.

Most ancient granites. — It is not half a century since the doctrine was very general that all granitic rocks were *primitive*, that is to say, that they originated before the deposition of the first sedimentary strata, and before the creation of organic beings (see Vol. I. p. 18.). But so greatly are our views now changed, that we find it no easy task to point out a single mass of granite demonstrably more ancient than all the known fossiliferous deposits. Could we discover some Lower Cambrian strata resting immediately on granite, there being no alterations at the point of contact, nor any intersecting granitic veins, we might then affirm the plutonic rock to have originated before the oldest known fossiliferous strata. Still it would be presumptuous to suppose that when a small part only of the globe has been investigated, we are acquainted with the oldest fossiliferous strata in the crust of our planet. Even when these are found, we cannot assume that there never were any antecedent strata containing organic remains, which may have become metamorphic. If we find pebbles

of granite in a conglomerate of the Lower Cambrian system, we may then feel assured that the parent granite was formed before the Lower Cambrian formation. But if the incumbent strata be merely Silurian or Upper Cambrian, the fundamental granite, although of high antiquity, may be posterior in date to *known* fossiliferous formations.

Protrusion of solid granite.—In part of Sutherlandshire, near Brora, common granite, composed of felspar, quartz, and mica, is in immediate contact with Oolitic strata, and has clearly been elevated to the surface at a period subsequent to the deposition of those strata.* Professor Sedgwick and Mr. Murchison conceive that this granite has been upheaved in a solid form; and that in breaking through the submarine deposits, with which it was not perhaps originally in contact, it has fractured them so as to form a breccia along the line of junction. This breccia consists of fragments of shale, sandstone, and limestone, with fossils of the oolite, all united together by a calcareous cement. The secondary strata, at some distance from the granite, are but slightly disturbed, but in proportion to their proximity the amount of dislocation becomes greater.

If we admit that solid hypogene rocks, whether

* Murchison, Geol. Trans., 2nd series, vol. ii. p. 307.

stratified or unstratified, have in such cases been driven upwards so as to pierce through yielding sedimentary deposits, we shall be enabled to account for many geological appearances otherwise inexplicable. Thus, for example, at Weinböhla and Hohnstein, near Meissen, in Saxony, a mass of granite has been observed covering strata of the Cretaceous and Oolitic periods for the space of between 300 and 400 yards square. It appears clearly from a recent memoir of Dr. B. Cotta on this subject*, that the granite was thrust into its actual position when solid. There are no intersecting veins at the junction — no alteration as if by heat, but evident signs of rubbing, and a breccia in some places, in which pieces of granite are mingled with broken fragments of the secondary rocks. As the granite overhangs both the lias and chalk, so the lias is in some places bent over strata of the cretaceous era.

Relative age of the granites of Arran. — In this island, the largest in the Firth of Clyde, being twenty miles in length from north to south, the four great classes of rocks, the fossiliferous, volcanic, plutonic, and metamorphic, are all conspicuously displayed within a very small area, and with their peculiar characters strongly contrasted. In the north of the island the granite rises to the

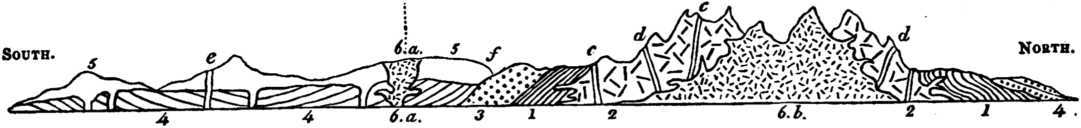
* Geognostische Wanderungen, Leipzig, 1838.

height of nearly 3000 feet above the sea, terminating in mountainous peaks. (See Section, Fig. 433.) On the flanks of the same mountains are chloritic-schists, blue roofing-slate, and other rocks of the metamorphic order (No. 1.), into which the granite (No. 2.) sends veins. This granite, therefore, is newer than the hypogene schists (No. 1.), which it penetrates.

These schists are highly inclined. Upon them rest beds of conglomerate and sandstone (No. 3.), which are referable to the Old Red formation, to which succeed various shales and limestones (No. 4.) containing the fossils of the Carboniferous period, upon which are other strata of sandstone and conglomerate (upper part of No. 4.), in which no fossils have been met with, which it is conjectured may belong to the New Red sandstone period. All the preceding formations are cut through by the volcanic rocks (No. 5.), which consist of greenstone, basalt, pitchstone, claystone-porphyry, and other varieties. These appear either in the form of dikes, or in dense masses from 50 to 700 feet in thickness, overlying the strata (No. 4.). They sometimes pass into syenite of so crystalline a form, that it may rank as a plutonic formation, and in one region, at Ploverfield, in Glen Cloy, a fine-grained granite (6. *a*.) is seen associated with the trap formation, and sending veins into the sandstone or into the upper strata of

General Section of Arran from north to south.

Fig. 433.



1. Metamorphic or Hypogene schists, the oldest formations in Arran.
2. Coarse-grained granite sending veins into the schists, No. 1.
3. Old Red Sandstone and Conglomerate containing pebbles exclusively derived from the rocks, No. 1., without any intermixture of granitic fragments.
4. Carboniferous strata and red sandstone (New Red?)
5. Trap, overlying and in dikes, passing occasionally into Syenites of the Plutonic class.

6. *a.* Fine-grained granite, associated with the overlying trap, No. 5.

6. *b.* Similar fine-grained granite, sending veins into the older granite, No. 2., and cutting off the trappean dikes, *c. d.**

* In the above section I have attempted to represent the new discoveries made since 1839, by Mr. Necker and Mr. A. C. Ramsay, in regard to the plutonic formations, 6. *a.* and 6. *b.*

No. 4. This interesting discovery of granite in the southern region of Arran, at a point where it is separated from the northern mass of granite by a great thickness of secondary strata and overlying trap, was made by Mr. L. A. Necker of Geneva, during his survey of Arran in 1839. We also learn from the recent investigations of Mr. A. C. Ramsay, that a similar fine-grained granite (No. 6. *b.*) appears in the interior of the northern granitic district, forming the nucleus of it, and sending veins into the older coarse grained granite (No. 2.) The trap dikes which penetrate the older granite are cut off, according to Mr. Ramsay, at the junction of the fine grained.

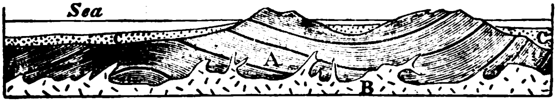
It is not improbable that the granite (No. 6. *b.*) may be of the same age as that of Ploverfield (No. 6. *a.*), and this again may belong to the same geological epoch as the trap formations (No. 5.). If there be any difference of date, it would seem that the fine-grained granite must be newer than the trappean rocks. But on the other hand, the coarser granite (No. 2.) may be the oldest rock in Arran, with the exception of the hypogene slates (No. 1.), into which it sends veins.

An objection may perhaps, at first, be started to this conclusion, derived from the curious and striking fact, the importance of which was first emphatically pointed out by Dr. MacCulloch, that no pebbles of granite occur in the conglomerates

of the red sandstone in Arran, although these conglomerates are several hundred feet in thickness, and lie at the foot of lofty granite mountains, which tower above them. As a general rule, all such aggregates of pebbles and sand are mainly composed of the wreck of pre-existing rocks occurring in the immediate vicinity. The total absence therefore of granitic pebbles has justly been a theme of wonder to those geologists who have successively visited Arran, and they have carefully searched there, as I have done myself, to find an exception, but in vain. The rounded masses consist exclusively of quartz, chlorite-schist, and other members of the metamorphic series; nor in the newer conglomerates of No. 4. have any granitic fragments been discovered. Are we then entitled to affirm that the coarse grained granite No. 2. like the fine grained variety No. 6. *a.* is more modern than all the other rocks of the island? This we cannot assume at present, but we may confidently infer that when the various beds of sandstone and conglomerate were formed, no granite had reached the surface, or had been exposed to denudation in Arran. It is clear that the crystalline schists were ground into sand and shingle when the strata No. 3. were deposited, and at that time the waves had never acted upon the granite, which now sends its veins into the schist. May we then conclude, that the

schists suffered denudation before they were invaded by granite? This opinion, although not inadmissible, is by no means fully borne out by the evidence. For at the time when the Old Red sandstone originated, the metamorphic strata may have formed islands in the sea, as in Fig. 434.,

Fig. 434.



over which the breakers rolled, or from which torrents and rivers descended, carrying down gravel and sand. The plutonic rock or granite (B) may even then have been previously injected at a certain depth below, and yet may never have been exposed to denudation.

As to the time and manner of the subsequent protrusion of the coarse-grained granite No. 2., this rock may have been thrust up bodily, in a solid form, during that long series of igneous operations which produced the trappean and plutonic formations, Nos. 5., 6. *a.*, and 6. *b.*

We have shewn that these eruptions, whatever their date, were posterior to the deposition of all the fossiliferous strata of Arran. We can also prove that subsequently both the granitic and trappean rocks underwent great aqueous denudation, which they probably suffered during

their emergence from the sea. The fact is demonstrated by the abrupt truncation of numerous dikes, such as those at *c*, *d*, *e*, which are cut off on the surface of the granite and trap. The overlying trap also ceases very abruptly on approaching the boundary of the great hypogene region, and terminates in a steep escarpment facing towards it as at *f*, Fig. 433. When in its original fluid state it could not have come thus suddenly to an end, but must have filled up the hollow now separating it from the hypogene rocks, had such a hollow then existed. This necessity of supposing that both the trap and the conglomerate once extended farther, and that veins such as *c*, *d*, (Fig. 433.) were once prolonged farther upwards, prepares us to believe that the whole of the northern granite may at one time have been covered by newer formations, under the pressure of which, before its protrusion, it assumed its highly crystalline texture.

The theory of the protrusion in a solid form of the northern nucleus of granite is confirmed by the manner in which the hypogene slates (No. 1.) and the beds of conglomerate (No. 3.) dip away from it on all sides. In some places indeed the slates are inclined towards the granite, but this exception might have been looked for because these hypogene strata have undergone disturbances at more than one geological epoch, and

may at some points, perhaps, have their original order of position inverted. The high inclination, therefore, and the quaquaversal dip of the beds around the borders of the granitic boss, and the comparative horizontality of the fossiliferous strata in the southern part of the island, are facts which all accord with the hypothesis of a great amount of movement at that point where the granite is supposed to have been thrust up bodily, and where we may conceive it to have been distended laterally by the repeated injection of fresh supplies of melted materials.*

* For the geology of Arran consult the works of Drs. Hutton and MacCulloch, the Memoirs of Messrs. Von Dechen and Oeynhausen, that of Professor Sedgwick and Mr. Murchison (Geol. Trans. 2d series), Mr. L. A. Necker's Memoir, read to the Royal Soc. of Edin. 20th April, 1840, and Mr. Ramsay's Geol. of Arran, 1841. I examined myself a large part of Arran in 1836.

CHAPTER XXXIV.

METAMORPHIC ROCKS.

General character of metamorphic rocks — Gneiss — Hornblende-schist — Mica-schist — Clay-slate — Quartzite — Chlorite-schist — Metamorphic limestone — Alphabetical list and explanation of other rocks of this family — Origin of the metamorphic strata — Their stratification is real and distinct from cleavage — On joints and slaty cleavage — Supposed causes of these structures — how far connected with crystalline action.

WE have now considered three distinct classes of rocks: first, the aqueous, or fossiliferous; secondly, the volcanic; and, thirdly, the plutonic, or granitic; and we have now lastly to examine those crystalline (or hypogene) strata to which the name of *metamorphic* has been assigned. The last-mentioned term expresses, as before explained, a theoretical opinion that such strata, after having been deposited from water, acquired by the influence of heat and other causes a highly crystalline texture.

These rocks, when in their most characteristic or normal state, are wholly devoid of organic remains, and contain no distinct fragments of other rocks whether rounded or angular. They sometimes break out in the central parts of narrow

mountain chains, but in other cases extend over areas of vast dimensions, occupying, for example, nearly the whole of Norway and Sweden, where, as in Brazil, they appear alike in the lower and higher grounds. In Great Britain those members of the series which approach most nearly to granite in their composition, as gneiss, mica-schist, and hornblende-schist, are confined to the country north of the rivers Forth and Clyde.

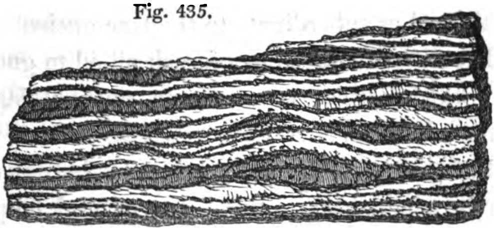
Many attempts have been made to trace a general order of succession or superposition in the members of this family; gneiss, for example, having been often supposed to hold invariably a lower geological position than mica-schist. But although such an order may prevail throughout limited districts, it is by no means universal, nor even general throughout the globe. To this subject, however, I shall again revert in the last chapter of this volume, when the chronological relations of the metamorphic rocks are pointed out.

The following may be enumerated as the principal members of the metamorphic class, — gneiss, mica-schist, hornblende-schist, clay-slate, chlorite-schist, hypogene or metamorphic limestone, and certain kinds of quartz rock or quartzite.

Gneiss. — The first of these, gneiss, may be called stratified granite, being formed of the same materials as granite, namely felspar, quartz, and mica. In the specimen here figured, the

white layers consist almost exclusively of granular felspar, with here and there a speck of mica and

Fig. 435.



Fragment of gneiss, natural size; section at right angles to planes of stratification.

grain of quartz. The dark layers are composed of grey quartz and black mica, with occasionally a grain of felspar intermixed. The rock splits most easily in the plane of these darker layers, and the surface thus exposed is almost entirely covered with shining spangles of mica. The accompanying quartz however greatly predominates in quantity, but the most ready cleavage is determined by the abundance of mica in certain parts of the dark layer.

Instead of these thin laminæ, gneiss is sometimes simply divided into thick beds, in which the mica has only a slight degree of parallelism to the planes of stratification.

The term "gneiss," however, in geology is commonly used in a wider sense to designate a formation in which the above-mentioned rock prevails, but with which any one of the other

metamorphic rocks, and more especially hornblende-schist, may alternate. These other members of the metamorphic series are, in this case, considered as subordinate to the true gneiss.

The different varieties of rock allied to gneiss, into which felspar enters as an essential ingredient, will be understood by referring to what was said of granite. Thus, for example, hornblende may be superadded to mica, quartz, and felspar, forming a syenitic gneiss; or talc may be substituted for mica, constituting talcose gneiss, a rock composed of felspar, quartz, and talc, in distinct crystals or grains (stratified protogine of the French).

Hornblende-schist is usually black, and composed principally of hornblende, with a variable quantity of felspar, and sometimes grains of quartz. When the hornblende and felspar are nearly in equal quantities, and the rock is not slaty, it corresponds in character with the greenstones of the trap family, and has been called "primitive greenstone." It may be termed hornblende rock. Some of these hornblendic masses may really have been volcanic rocks, which have since assumed a more crystalline or metamorphic texture.

Mica-schist, or *micaceous schist*, is, next to gneiss, one of the most abundant rocks of the metamorphic series. It is slaty, essentially composed of mica and quartz, the mica sometimes appearing

to constitute the whole mass. Beds of pure quartz also occur in this formation. In some districts garnets in regular twelve-sided crystals form an integrant part of mica-schist. This rock passes by insensible gradations into clay-slate.

Clay-slate, or Argillaceous schist.—This rock resembles an indurated clay or shale, is for the most part extremely fissile, often affording good roofing slate. It may consist of the ingredients of gneiss, or of an extremely fine mixture of mica and quartz, or talc and quartz. Occasionally it derives a shining and silky lustre from the minute particles of mica or talc which it contains. It varies from greenish or bluish-grey to a lead colour. It may be said of this, more than of any other schist, that it is common to the metamorphic and fossiliferous series, for some clay-slates taken from each division would not be distinguishable by mineralogical characters.

Quartzite, or Quartz rock, is an aggregate of grains of quartz, which are either in minute crystals, or in many cases slightly rounded, occurring in regular strata associated with gneiss or other metamorphic rocks. Compact quartz, like that so frequently found in veins, is also found together with granular quartzite. Both of these alternate with gneiss or mica-schist, or pass into those rocks by the addition of mica, or of felspar and mica.

Chlorite-schist is a green slaty rock in which

chlorite is abundant in foliated plates, usually blended with minute grains of quartz, or sometimes with felspar or mica. Often associated with, and graduating into, gneiss and clay-slate.

Hypogene or metamorphic limestone.—This rock, commonly called *primary limestone*, is sometimes a thick bedded white crystalline granular marble used in sculpture; but more frequently it occurs in thin beds, forming a foliated schist much resembling in colour and appearance certain varieties of gneiss and mica-schist. It alternates with both these rocks, and in like manner with argillaceous schist. It then usually contains some crystals of mica, and occasionally quartz, felspar, hornblende, and talc. This member of the metamorphic series enters sparingly into the structure of the hypogene districts of Norway, Sweden, and Scotland, but is largely developed in the Alps.

Before offering any further observations on the probable origin of the metamorphic rocks, I subjoin in the form of a glossary, a brief explanation of some of the principal varieties and their synonymes.

Actinolite-schist. A slaty foliated rock, composed chiefly of actinolite, (an emerald-green mineral, allied to hornblende,) with some admixture of felspar, or quartz, or mica.

Ampelite. Aluminous slate (Brongniart); occurs both in the metamorphic and fossiliferous series.

Amphibolite. Hornblende rock, which see.

Argillaceous-schist, or Clay-slate. *See* p. 383.

Arkose. Term used by Brongniart for granular Quartzite, which see.

Chiastolite-slate scarcely differs from clay-slate, but includes numerous crystals of Chiastolite; in considerable thickness in Cumberland. Chiastolite occurs in long slender rhomboidal crystals. For composition, see Table, p. 210.

Chlorite-schist. A green slaty rock, in which chlorite, a green scaly mineral, is abundant. *See* p. 383.

Clay-slate, or Argillaceous-schist. *See* p. 383.

Eurite and Euritic Porphyry. A base of compact felspar, with grains of laminar felspar, and often mica and other minerals disseminated (Brongniart). M. D'Aubuisson regards eurite as an extremely fine-grained granite, in which felspar predominates, the whole forming an apparently homogeneous rock. Eurite has been already mentioned as a plutonic rock, but occurs also in beds subordinate to gneiss or mica-slate.

Gneiss. A stratified or laminated rock, same composition as granite. *See* p. 380.

Hornblende Rock, or Amphibolite. Composed of hornblende and felspar. The same composition as hornblende schist, stratified, but not fissile. *See* p. 207.

Hornblende-schist, or Slate. Composed chiefly of hornblende, with occasionally some felspar. *See* p. 382.

Hornblendic or Syenitic Gneiss. Composed of felspar, quartz, and hornblende.

Hypogene Limestone. *See* p. 384.

Marble. *See* p. 384.

Mica-schist, or Micaceous-schist. A slaty rock, composed of mica and quartz in variable proportions. *See* p. 382.

Mica-slate. *See* Mica-schist, p. 382.

Phyllade. D'Aubuisson's term for clay-slate, from φυλλας, a heap of leaves.

Primary Limestone. *See* Hypogene Limestone, p. 384.

PROTOGINE. *See* TALCOSE-GNEISS, p. 382.; when unstratified it is Talcose-granite.

QUARTZ ROCK, or QUARTZITE. A stratified rock; an aggregate of grains of quartz. *See* p. 383.

SERPENTINE occurs in both divisions of the hypogene series, as a stratified or unstratified rock; contains much magnesia; is chiefly composed of the mineral called serpentine, mixed with diallage, talc, and steatite. The pure varieties of this rock, called noble serpentine, consist of a hydrated silicate of magnesia, generally of a greenish colour; this base is commonly mixed with oxide of iron.

TALCOSE-GNEISS. Same composition as talcose-granite or protogine, but either stratified or laminated. *See* p. 382.

TALCOSE-SCHIST consists chiefly of talc, or of talc and quartz, or of talc and felspar, and has a texture something like that of clay-slate.

WHITESTONE. Same as Eurite.

Origin of the Metamorphic Strata.

Having said thus much of the mineral composition of the metamorphic rocks, I may combine what remains to be said of their structure and history with an account of the opinions entertained of their probable origin. At the same time it may be well to forewarn the reader that we are here entering upon ground of controversy, and soon reach the limits where positive induction ends, and beyond which we can only indulge in speculations. It was once a favourite doctrine, and is still maintained by many, that these rocks owe

their crystalline texture, their want of all signs of a mechanical origin, or of fossil contents, to a peculiar and nascent condition of the planet at the period of their formation. The arguments in refutation of this hypothesis will be more fully considered when I show, in the last chapter of this volume, to how many different ages the metamorphic formations are referable, and how gneiss, mica-schist, clay-slate, and hypogene limestone (that of Carrara for example), have been formed, not only since the first introduction of organic beings into this planet, but even long after many distinct races of plants and animals had passed away in succession.

The doctrine respecting the crystalline strata, implied in the name metamorphic, may properly be treated of in this place; and we must first inquire whether these rocks are really entitled to be called stratified in the strict sense of having been originally deposited as sediment from water. The general adoption by geologists of the term stratified, as applied to these rocks, sufficiently attests their division into beds very analogous, at least in form, to ordinary fossiliferous strata. This resemblance is by no means confined to the existence in both of an occasional slaty structure, but extends to every kind of arrangement which is compatible with the absence of fossils, and of sand, pebbles, ripple-mark, and other characters which

the metamorphic theory supposes to have been obliterated by plutonic action. Thus, for example, we behold alike in the crystalline and fossiliferous formations an alternation of beds varying greatly in composition, colour, and thickness. We observe, for instance, gneiss alternating with layers of black hornblende-schist, or with granular quartz, or limestone; and the interchange of these different strata may be repeated for an indefinite number of times. In the like manner, mica-schist alternates with chlorite-schist, and with granular limestone in thin layers.

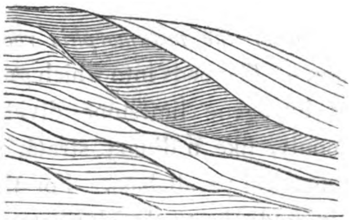
As in fossiliferous formations strata of pure siliceous sand alternate with micaceous sand and with layers of clay, so in the crystalline or metamorphic rocks we have beds of pure quartzite alternating with mica-schist and clay-slate. As in the secondary and tertiary series we meet with limestone alternating again and again with micaceous or argillaceous sand, so we find in the hypogene, gneiss and mica-schist alternating with pure and impure granular limestones.

It has also been shown that the ripple-mark is very commonly repeated throughout a considerable thickness of fossiliferous strata; so in mica-schist and gneiss, there is sometimes an undulation of the laminæ on a minute scale, which may, perhaps, be a modification of similar inequalities in the original deposit.

In the crystalline formations also, as in many of the sedimentary before described, single strata are sometimes made up of laminæ placed diagonally, such laminæ not being regularly parallel to the planes of cleavage.

This disposition of the layers is illustrated in the accompanying diagram, in which I have re-

Fig. 436.



Lamination of clay-slate, Montagne de Seguinat, near Gavarnie, in the Pyrenees.

presented carefully the stratification of a coarse argillaceous schist, which I examined in the Pyrenees, part of which approaches in character to a green and blue roofing slate, while part is extremely quartzose, the whole mass passing downwards into micaceous schist. The vertical section here exhibited is about three feet in height, and the layers are sometimes so thin that fifty may be counted in the thickness of an inch. Some of them consist of pure quartz.

The inference drawn from the phenomena above described, in favour of the aqueous origin of clay-slate and other crystalline strata, is greatly

strengthened by the fact that many of these metamorphic rocks occasionally alternate with, and sometimes pass by intermediate gradations into, rocks of a decidedly mechanical origin, and exhibiting traces of organic remains. The fossiliferous formations, moreover, into which this passage is effected, are by no means invariably of the same age nor of the highest antiquity, as will be afterwards explained.

Stratification of the metamorphic rocks distinct from cleavage. — The beds into which gneiss, mica-schist, and hypogene limestone divide, exhibit most commonly, like ordinary strata, a want of perfect geometrical parallelism. For this reason, therefore, in addition to the alternate recurrence of layers of distinct materials, the stratified arrangement of the crystalline rocks cannot be explained away by supposing it to be simply a divisional structure like that to which we owe some of the slates used for writing and roofing. *Slaty cleavage*, as it has been called, has in many cases been produced by the regular deposition of thin plates of fine sediment one upon another; but there are many instances where it is decidedly unconnected with such a mode of origin, and where it is not even confined to the aqueous formations. Some kinds of trap, for example, as clinkstone, split into laminæ, and are used for roofing.

There are, says Professor Sedgwick, three dis-

tinct forms of structure exhibited in certain rocks throughout large districts: viz.— First, stratification; secondly, joints; and thirdly, slaty cleavage; the two last having no connection with true bedding, and having been superinduced by causes absolutely independent of gravitation. All these different structures must have different names, even though there be some cases where it is impossible, after carefully studying the appearances, to decide upon the class to which they belong.*

Joints. — Now, in regard to the second of these forms of structure or joints, they are natural fissures which often traverse rocks in straight and well-determined lines. They afford to the quarryman, as Mr. Murchison observes, when speaking of the phenomena, as exhibited in Shropshire and the neighbouring counties, the greatest aid in the extraction of blocks of stone; and, if a sufficient number cross each other, the whole mass of rock is split into symmetrical blocks.† The faces of the joints are for the most part smoother and more regular than the surfaces of true strata. The joints are straight-cut chinks, often slightly open, often passing, not only through layers of successive deposition, but also through balls of limestone or other matter which have been formed

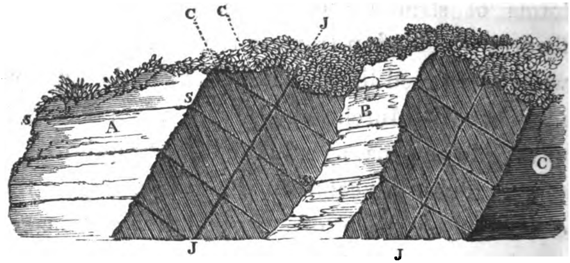
* Geol. Trans., Second Series, vol. iii. p. 480.

† The Silurian System of Rocks, as developed in Salop, Hereford, &c., p. 245.

by concretionary action, since the original accumulation of the strata. Such joints, therefore, must often have resulted from one of the last changes superinduced upon sedimentary deposits.*

In the annexed diagram the flat surfaces of rock A, B, C, represent exposed faces of joints, to which the walls of other joints, J J, are parallel. S S are the lines of stratification; C C are lines of slaty cleavage, which intersect the rock at a considerable angle to the planes of stratification.

Fig. 437.



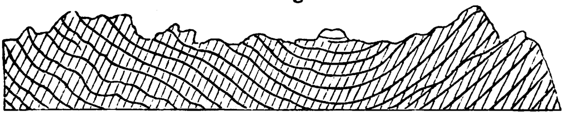
Stratification, joints, and cleavage.

Joints, according to Professor Sedgwick, are distinguishable from lines of slaty cleavage in this, that the rock intervening between two joints has no tendency to cleave in a direction parallel to the planes of the joints, whereas a rock is capable of indefinite subdivision in the direction of its slaty cleavage. In some cases where the strata

* The Silurian System of Rocks, as developed in Salop, Hereford, &c., p. 246.

are curved, the planes of cleavage are still perfectly parallel. This has been observed in the slate rocks of part of Wales (see Fig. 438.), which

Fig. 438.



Parallel planes of cleavage intersecting curved strata. (Sedgwick.)

consist of a hard greenish slate. The true bedding is there indicated by a number of parallel stripes, some of a lighter and some of a darker colour than the general mass. Such stripes are found to be parallel to the true planes of stratification, wherever these are manifested by ripple-mark, or by beds containing peculiar organic remains. Some of the contorted strata are of a coarse mechanical structure, alternating with fine-grained crystalline chloritic slates, in which case the same slaty cleavage extends through the coarser and finer beds, though it is brought out in greater perfection in proportion as the materials of the rock are fine and homogeneous. It is only when these are very coarse that the cleavage planes entirely vanish. These planes are usually inclined at a very considerable angle to the planes of the strata. In the Welsh chains, for example, the average angle is as much as from 30° to 40°. Sometimes the cleavage planes dip towards the same point of the compass as those of stratification, but

more frequently to opposite points. It may be stated as a general rule, that when beds of coarser materials alternate with those composed of finer particles, the slaty cleavage is either entirely confined to the fine-grained rock, or is very imperfectly exhibited in that of coarser texture. This rule holds, whether the cleavage is parallel to the planes of stratification or not.

In the Swiss and Savoy Alps, as Mr. Bakewell has remarked, enormous masses of limestone are cut through so regularly by nearly vertical partings, and these are often so much more conspicuous than the seams of stratification, that an unexperienced observer will almost inevitably confound them, and suppose the strata to be perpendicular in places where in fact they are almost horizontal.*

Now these joints are supposed to be analogous to those partings which have been already observed to separate volcanic and plutonic rocks into cuboidal and prismatic masses. On a small scale we see clay and starch when dry split into similar shapes, which is often caused by simple contraction, whether the shrinking be due to the evaporation of water, or to a change of temperature. It is well known that many sandstones and other rocks expand by the application of mo-

* Introduction to Geology, chap. iv.

derate degrees of heat, and then contract again on cooling; and there can be no doubt that large portions of the earth's crust have, in the course of past ages, been subjected again and again to very different degrees of heat and cold. These alternations of temperature have probably contributed largely to the production of joints in rocks.

In some countries, as in Saxony, where masses of basalt rest on sandstone, the aqueous rock has for the distance of several feet from the point of junction assumed a columnar structure similar to that of the trap. In like manner some hearthstones, after exposure to the heat of a furnace without being melted, have become prismatic. Certain crystals also acquire by the application of heat a new internal arrangement, so as to break in a new direction, their external form remaining unaltered.

Scoresby, when speaking of the icebergs of Spitzbergen, states that "they are full of rents, extending perpendicularly downwards, and dividing them into innumerable columns." Colonel Jackson, who has lately investigated this subject more attentively, found that the ice on the Neva, at St. Petersburg, at the beginning of a thaw, when two feet in thickness, is traversed by rows of very minute air-bubbles extending in straight lines, sometimes a little inflected, from the upper circle of the ice towards the lower, within from two to five inches

of which they terminate. "Other blocks presented these bubbles united, so as to form cylindrical canals, a little thicker than a horsehair. Observing still further," he says, "I found blocks in which the process was more advanced, and two, three, or more clefts, struck off in different directions from the vertical veins, so that a section perpendicular to the vein would represent in miniature the star-formed cracks of timber. Finally, in some pieces, these cracks united from top to bottom of the veins, separating the whole mass into vertical prisms, having a greater or less number of sides. In this state a slight shock was sufficient to detach them; and the block with its scattered fragments was in all respects the exact miniature resemblance, in crystal, of a Giant's Causeway. The surface was like a tessellated pavement, and the columns rose close, adhering and parallel, from the compact mass of a few inches at the under surface. More or less time is required for the process, which I have since seen in all its different stages."*

Here again we find the columnar or jointed structure in a solid mass, which had been subjected to great changes of temperature.

It seems, therefore, that the fissures called joints may have been the result of different causes, as of some modification of crystalline action, or simple

* Journ. of Roy. Geograph. Soc., vol. v. p. 19.

contraction during consolidation, or during a change of temperature. And there are cases where joints may have been due to mechanical violence, and the strain exerted on strata during their upheaval, or when they have sunk down below their former level. Professor Phillips has suggested that the previous existence of divisional planes may often have determined, and must greatly have modified, the lines and points of fracture caused in rocks by those forces to which they owe their elevation or dislocations. These lines and points being those of least resistance, cannot fail to have influenced the direction in which the solid mass would give way on the application of external force.

It has been observed by Mr. Murchison, that in referring both joints and slaty cleavage to crystalline action, we are borne out by a well-known analogy in which crystallization has in like manner given rise to two distinct kinds of structure in the same body. Thus, for example, in a six-sided prism of quartz, the planes of cleavage are distinct from those of the prism. It is impossible to cleave the crystals parallel to the plane of the prism, just as slaty rocks cannot be cleaved parallel to the joints; but the quartz crystal, like the older schists, may be cleaved *ad infinitum* in the direction of the cleavage planes.*

* Silurian System of Rocks, &c., p. 246.

I have already stated that extremely fine slates, like those of the Niesen, near the Lake of Thun, in Switzerland, are perfectly parallel to the planes of stratification, and are, therefore, probably due to successive aqueous deposition. Even when the slates are oblique to the general planes of the strata, it by no means follows as a matter of course that they have been caused by crystalline action, for they may be the result of that diagonal lamination which I have before described (p. 35.). In this case, however, there is usually much irregularity, whereas those cleavage planes oblique to the true stratification, which are referred to a crystalline action, are often perfectly symmetrical, and observe a strict geometrical parallelism, even when the strata are contorted, as already described (p. 393.).

In regard to the origin of slaty cleavage, where it is unconnected with sedimentary deposition, Professor Sedgwick is of opinion that no retreat of parts, no contraction in dimensions, in passing to a solid state, can account for the phenomenon. It must be referred to crystalline or polar forces acting simultaneously and somewhat uniformly, in given directions, on large masses having a homogeneous composition.

A fact recorded by Mr. Darwin affords confirmation to this theory. The ore of the gold mines of Yaquil, in Chili, is ground in a mill into

an impalpable powder. After this powder has been washed, and nearly all the metal separated, the mud which passes from the mills is collected into pools, where it subsides, and is cleared out and thrown into a common heap. A great deal of chemical action then commences, salts of various kinds effloresce on the surface, and the mass becomes hard, and divides into concretionary fragments. These fragments were observed to possess *an even and well-defined slaty structure;* but the laminæ were not inclined at any uniform angle.*

Mr. R. W. Fox lately submitted a mass of moist clay, worked up with acidulated water, to weak voltaic action for some months, and it was found when dry to be rudely laminated, the planes of the slightly undulating laminæ being at right angles to the direction of the electrical forces.†

Sir John Herschel, in allusion to slaty cleavage, has suggested, "that if rocks have been so heated as to allow a commencement of crystallization; that is to say, if they have been heated to a point at which the particles can begin to move amongst themselves, or at least on their own axes, some general law must then determine the position in which these particles will rest on cooling. Pro-

* Journal of Travels in S. America, &c., p. 234.

† Although the lamination in the specimen shown to me was very imperfect, it was sufficiently evident to encourage farther experiments.

bably that position will have some relation to the direction in which the heat escapes. Now, when all, or a majority of particles of the same nature, have a general tendency to one position, that must of course determine a cleavage plane. Thus we see the infinitesimal crystals of fresh precipitated sulphate of barytes, and some other such bodies, arrange themselves alike in the fluid in which they float; so as, when stirred, all to glance with one light, and give the appearance of silky filaments. Some sorts of soap, in which insoluble margarates * exist, exhibit the same phenomenon when mixed with water; and what occurs in our experiments on a minute scale may occur in nature on a great one."†

* Margaric acid is an oleaginous acid, formed from different animal and vegetable fatty substances. A margarate is a compound of this acid with soda, potash, or some other base, and is so named from its pearly lustre.

† Letter to the author, dated Cape of Good Hope, Feb. 20. 1836.

CHAPTER XXXV.

METAMORPHIC ROCKS — *continued.*

Strata near some intrusive masses of granite converted into rocks identical with different members of the metamorphic series — Arguments hence derived as to the nature of plutonic action — Time may enable this action to pervade denser masses — From what kinds of sedimentary rock each variety of the metamorphic class may be derived — Certain objections to the metamorphic theory considered.

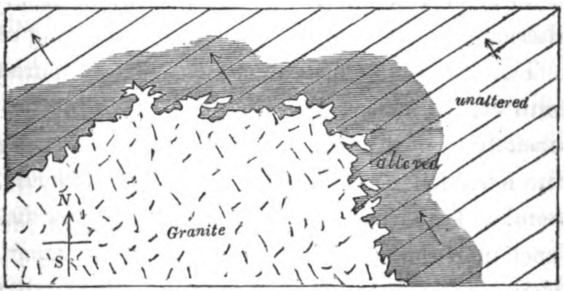
It has been seen that geologists have been very generally led to infer, from the phenomena of joints and slaty cleavage, that mountain masses, of which the sedimentary origin is unquestionable, have been acted upon simultaneously by vast crystalline forces. That the structure of fossiliferous strata has often been modified by some general cause since their original deposition, and even subsequently to their consolidation and dislocation, is undeniable. These facts prepare us to believe that still greater changes may have been worked out by a greater intensity, or more prolonged development of the same agency, combined, perhaps, with other causes. Now we have seen that, near the immediate contact of granitic veins and volcanic dikes, very extraordinary alterations in rocks have taken place, more especially

in the neighbourhood of granite. It will be useful here to add other illustrations, showing that a texture undistinguishable from that which characterizes the more crystalline metamorphic formations, has actually been superinduced in strata once fossiliferous.

In the southern extremity of Norway there is a large district, on the west side of the fiord of Christiania, in which granite or syenite protrudes in mountain masses through fossiliferous strata, and usually sends veins into them at the point of contact. The stratified rocks, replete with shells and zoophytes, consist chiefly of shale, limestone, and some sandstone, and all these are invariably altered near the granite for a distance of from 50 to 400 yards. The aluminous shales are hardened and have become flinty. Sometimes they resemble jasper. Ribboned jasper is produced by the hardening of alternate layers of green and chocolate-coloured schist, each stripe faithfully representing the original lines of stratification. Nearer the granite the schist often contains crystals of hornblende, which are even met with in some places for a distance of several hundred yards from the junction; and this black hornblende is so abundant, that eminent geologists, when passing through the country, have confounded it with the ancient hornblende-schist, subordinate to the great gneiss formation of Norway. Frequently, between the

granite and the hornblende slate, above mentioned, grains of mica and crystalline felspar appear in the schist, so that rocks resembling gneiss and mica-schist are produced. Fossils can rarely be detected in these schists, and they are more completely effaced in proportion to the more crystalline texture of the beds, and their vicinity to the granite. In some places the siliceous matter of the schist becomes a granular quartz; and when hornblende and mica are added, the altered rock loses its stratification, and passes into a kind of granite. The limestone, which at points remote from the granite is of an earthy texture, blue colour, and often abounds in corals, becomes a white granular marble near the granite, sometimes

Fig. 439.



Altered zone of fossiliferous slate and limestone near granite. Christiania.

The arrows indicate the dip, and the straight lines the strike, of the beds.

siliceous, the granular structure extending occasionally upwards of 400 yards from the junction;

and the corals being for the most part obliterated, though sometimes preserved, even in the white marble. Both the altered limestone and hardened slate contain garnets in many places, also ores of iron, lead, and copper, with some silver. These alterations occur equally, whether the granite invades the strata in a line parallel to the general strike of the fossiliferous beds, or in a line at right angles to their strike, as will be seen by the accompanying ground plan.*

The indurated and ribboned schists above mentioned bear a strong resemblance to certain shales of the coal found at Russell's Hall, near Dudley, where coal mines have been on fire for ages. Beds of shale of considerable thickness, lying over the burning coal, have been baked and hardened so as to acquire a flinty fracture, the layers being alternately green and brick-coloured.

The granite of Cornwall, in like manner, sends forth veins into a coarse argillaceous-schist, provincially termed killas. This killas is converted into hornblende-schist near the contact with the veins. These appearances are well seen at the junction of the granite and killas, in St. Michael's Mount, a small island nearly 300 feet high, situated in the bay, at a distance of about three miles from Penzance.

* Keilhau, Gæa Norvegica, pp. 61—63.

The granite of Dartmoor, in Devonshire, says Mr. De la Beche, has intruded itself into the slate and slaty sandstone called greywacké, twisting and contorting the strata, and sending veins into them. Hence some of the slate rocks have become "micaceous; others more indurated, and with the characters of mica-slate and gneiss; while others again appear converted into a hard-zoned rock strongly impregnated with felspar."*

We learn from the investigations of M. Dufrénoy, that in the eastern Pyrenees there are mountain masses of granite posterior in date to the formations called lias and chalk of that district, and that these fossiliferous rocks are greatly altered in texture, and often charged with iron-ore, in the neighbourhood of the granite. Thus in the environs of St. Martin, near St. Paul de Fénouillet, the chalky limestone becomes more crystalline and saccharoid as it approaches the granite, and loses all trace of the fossils which it previously contained in abundance. At some points, also, it becomes dolomitic, and filled with small veins of carbonate of iron, and spots of red iron-ore. At Rancié the lias nearest the granite is not only filled with iron-ore, but charged with pyrites, tremolite, garnet, and a new mineral somewhat

* Geol. Manual, p. 479.

allied to felspar, called, from the place in the Pyrenees where it occurs, "couzeranite."

Now the alterations above described as superinduced in rocks by volcanic dikes and granite veins, prove incontestably that powers exist in nature capable of transforming fossiliferous into crystalline strata, — powers capable of generating in them a new mineral character, similar, nay, often absolutely identical with that of gneiss, mica-schist, and other stratified members of the hypogene series. The precise nature of these altering causes, which may provisionally be termed plutonic, is in a great degree obscure and doubtful; but their reality is no less clear, and we must suppose the influence of heat to be in some way connected with the transmutation, if, for reasons before explained, we concede the igneous origin of granite.

The experiments of Gregory Watt, in fusing rocks in the laboratory, and allowing them to consolidate by slow cooling, prove distinctly that a rock need not be perfectly melted in order that a re-arrangement of its component particles should take place, and a partial crystallization ensue.* We may easily suppose, therefore, that all traces of shells and other organic remains may be destroyed; and that new chemical combinations

* Phil. Trans. 1804.

may arise, without the mass being so fused as that the lines of stratification should be wholly obliterated.

We must not, however, imagine that heat alone, such as may be applied to a stone in the open air, can constitute all that is comprised in plutonic action. We know that volcanos in eruption not only emit fluid lava, but give off steam and other heated gases, which rush out in enormous volume, for days, weeks, or years continuously, and are even disengaged from lava during its consolidation. When the materials of granite, therefore, came in contact with the fossiliferous stratum in the bowels of the earth under great pressure, the contained gases might be unable to escape; yet when brought into contact with rocks, might pass through their pores with greater facility than water is known to do. (See vol. i. p. 76.) These aeriform fluids, such as sulphuretted hydrogen, muriatic acid, and carbonic acid, issue in many places from rents in rocks, which they have discoloured and corroded, softening some and hardening others. If the rocks are charged with water, they would pass through more readily; for, according to the experiments of Henry, water, under an hydrostatic pressure of ninety-six feet, will absorb three times as much carbonic acid gas as it can under the ordinary pressure of the atmosphere. Although this increased power of absorption would be diminished, in consequence of the

higher temperature found to exist as we descend in the earth, yet Professor Bischoff has shown that the heat by no means augments in such a proportion as to counteract the effect of augmented pressure.* There are other gases, as well as the carbonic acid, which water absorbs, and more rapidly in proportion to the amount of pressure. Now even the most compact rocks may be regarded, before they have been exposed to the air and dried, in the light of sponges filled with water; and it is conceivable that heated gases brought into contact with them, at great depths, may be absorbed readily, and transfused through their pores. Although the gaseous matter first observed would soon be condensed, and part with its heat, yet the continual arrival of fresh supplies from below might, in the course of ages, cause the temperature of the water, and with it that of the containing rock, to be materially raised.

M. Fournet, in his description of the metalliferous gneiss near Clermont, in Auvergne, states that all the minute fissures of the rock are quite saturated with free carbonic acid gas, which rises plentifully from the soil there and in many parts of the surrounding country. The various elements of the gneiss, with the exception of the quartz, are all softened; and new combinations of the

* Poggendorf's Annalen, No. XVI. Second Series, vol. iii.

acid, with lime, iron, and manganese, are continually in progress.*

Another illustration of the power of subterranean gases is afforded by the stufas of St. Calogero, situated in the largest of the Lipari Islands. Here, according to the description published by Hoffmann, horizontal strata of tuff, extending for four miles along the coast, and forming cliffs more than 200 feet high, have been discoloured in various places, and strangely altered by the "all-penetrating vapours." Dark clays have become yellow, or often snow-white; or have assumed a chequered and brecciated appearance, being crossed with ferruginous red stripes. In some places the fumeroles have been found by analysis to consist partly of sublimations of oxide of iron; but it also appears that veins of calcedony and opal, and others of fibrous gypsum, have resulted from these volcanic exhalations.†

The reader may also refer to M. Virlet's account of the corrosion of hard, flinty, and jaspideous rocks near Corinth, by the prolonged agency of subterranean gases ‡; and to Dr. Daubeny's description of the decomposition of trachytic rocks

* See Principles, *Index*, "Carbonated Springs," &c.

† Hoffmann's Liparischen Inseln, p. 38. Leipzig, 1832.

‡ See Princ. of Geol.; and Bulletin de la Soc. Géol. de France, tom. ii. p. 330.

in the Solfatara, near Naples, by sulphuretted hydrogen and muriatic acid gases.*

Although in all these instances we can only study the phenomena as exhibited at the surface, it is clear that the gaseous fluids must have made their way through the whole thickness of porous or fissured rocks, which intervene between the subterranean reservoirs of gas and the external air. The extent, therefore, of the earth's crust, which the vapours have permeated and are now permeating, may be thousands of fathoms in thickness, and their heating and modifying influence may be spread throughout the whole of this solid mass.

We learn from Professor Bischoff that the steam of a hot spring at Aix-la-Chapelle, although its temperature is only from 133° to 167° F., has converted the surface of some blocks of black marble into a doughy mass. He conceives, therefore, that steam in the bowels of the earth having a temperature equal or even greater than the melting point of lava, and having an elasticity of which even Papin's digester can give but a faint idea, may convert rocks into melted liquid matter. †

The above observations are calculated to meet

* See Princ. of Geol.; and Daubeny's Volcanos, p. 167.
† Jam. Ed. New Phil. Journ., No. 51. p. 43.

some of the objections which have been urged against the metamorphic theory on the ground of the small power of rocks to conduct heat; for it is well known that rocks, when dry and in the air, differ remarkably from metals in this respect. It has been asked how the changes which extend merely for a few feet from the contact of a dike could have penetrated through mountain masses of crystalline strata several miles in thickness. Now it has been stated that the plutonic influence of the syenite of Norway, has sometimes altered fossiliferous strata for a distance of a quarter of a mile, both in the direction of their dip and of their strike. (See Fig. 439. p. 403.) This is undoubtedly an extreme case; but is it not far more philosophical to suppose that this influence may, under favourable circumstances, affect denser masses, than to invent an entirely new cause to account for effects merely differing in quantity, and not in kind? The metamorphic theory does not require us to affirm that some contiguous mass of granite has been the altering power; but merely that an action, existing in the interior of the earth at an unknown depth, whether thermal, electrical, or other, analogous to that exerted near intruding masses of granite, has, in the course of vast and indefinite periods, and when rising perhaps from a large heated surface, reduced strata thousands of yards thick to a state of semi-fusion, so that on

cooling they have become crystalline, like gneiss. Granite may have been another result of the same action in a higher state of intensity, by which a thorough fusion has been produced; and in this manner the passage from granite into gneiss may be explained.

Some geologists are of opinion, that the alternate layers of mica and quartz, or mica and felspar, or lime and felspar, are so much more distinct in certain metamorphic rocks, than the ingredients composing alternate layers in many sedimentary deposits, that the similar particles must be supposed to have exerted a molecular attraction for each other, and to have thus congregated together in layers, more distinct in mineral composition than before they were crystallized.

In considering, then, the various data already enumerated, the forms of stratification in metamorphic rocks, their passage on the one hand into the fossiliferous, and on the other into the plutonic formations, and the conversions which can be ascertained to have occurred in the vicinity of granite, we may conclude that gneiss and mica-schist may be nothing more than altered micaceous and argillaceous sandstones, that granular quartz may have been derived from siliceous sandstone, and compact quartz from the same materials. Clay-slate may be altered shale, and granular marble may have originated in the form of ordi-

nary limestone, replete with shells and corals, which have since been obliterated; and, lastly, calcareous sands and marls may have been changed into impure crystalline limestones.

"Hornblende-schist, says Dr. MacCulloch, "may at first have been mere clay; for clay or shale is found altered by trap into Lydian stone, a substance differing from hornblende-schist almost solely in compactness and uniformity of texture."* "In Shetland," remarks the same author, "argillaceous-schist (or clay-slate), when in contact with granite, is sometimes converted into hornblende-schist, the schist becoming first siliceous, and ultimately, at the contact, hornblende-schist."†

The anthracite found associated with hypogene rocks may have been coal; for we know that, in the vicinity of some trap dikes, coal is converted into anthracite.

The total absence of any trace of fossils has inclined many geologists to attribute the origin of crystalline strata to a period antecedent to the existence of organic beings. Admitting, they say, the obliteration, in some cases, of fossils by plutonic action, we might still expect that traces of them would oftener occur in certain ancient systems of slate, in which, as in Cumberland, some conglomerates occur. But in urging this argument, it

* Syst. of Geol., vol. i. p. 210. † Ibid., p. 211.

seems to have been forgotten, that there are stratified formations of enormous thickness, and of various ages, and some of them very modern, all formed after the earth had become the abode of living creatures, which are nevertheless in certain districts entirely destitute of all vestiges of organic bodies. In some, the traces of fossils may have been effaced by water and acids, at many successive periods; and it is clear, that the older the stratum, the greater is the chance of its being non-fossiliferous, even if it has escaped all metamorphic action.

It has been also objected to the metamorphic theory, that the chemical composition of the secondary strata differs essentially from that of the crystalline schists, into which they are supposed to be convertible.* The "primary" schists, it is said, usually contain a considerable proportion of potash or of soda, which the secondary clays, shales, and slates do not, these last being the result of the decomposition of felspathic rocks, from which the alkaline matter has been abstracted during the process of decomposition. But this reasoning proceeds on insufficient and apparently mistaken data; for a large portion of what is usually called clay, marl, shale, and slate does actually contain a certain and often a considerable proportion of

* Dr. Boase, Primary Geology, p. 319.

alkali; so that it is difficult in many countries to obtain clay or shale sufficiently free from alkaline ingredients to allow of their being burnt into bricks or used for pottery.

Thus the argillaceous shales, as they are called, and slates of the Old Red sandstone, in Forfarshire and other parts of Scotland, are so much charged with alkali, derived from triturated felspar, that, instead of hardening when exposed to fire, they sometimes melt into a glass. They contain no lime, but appear to consist of extremely minute grains of the various ingredients of granite, which are distinctly visible in the coarser-grained varieties, and in almost all the interposed sandstones. These laminated clays, marls, and shales might certainly, if crystallized, resemble in composition many of the primary strata.

There is also potash in the vegetable remains included in strata, and soda in the salts by which they are sometimes so largely impregnated, as in Patagonia.

Another objection has been derived from the alternation of highly crystalline strata with others having a less crystalline texture. The heat, it is said, in its ascent from below, must have traversed the less altered schists before it reached a higher and more crystalline bed. In answer to this, it may be observed, that if a number of strata differing greatly in composition from each other be

subjected to equal quantities of heat, there is every probability that some will be more fusible than others. Some, for example, will contain soda, potash, lime, or some other ingredient capable of acting as a flux; while others may be destitute of the same elements, and so refractory as to be very slightly affected by a degree of heat capable of reducing others to semi-fusion. Nor should it be forgotten that, as a general rule, the less crystalline rocks do really occur in the upper, and the more crystalline in the lower part of each metamorphic series.

But it will be impossible for the reader duly to appreciate the propriety of the term metamorphic, as applied to the strata hitherto called primary, until I have shown in the next chapter, that these crystalline strata have been formed at a great variety of distinct periods.

CHAPTER XXXVI.

ON THE DIFFERENT AGES OF THE METAMORPHIC ROCKS.

Age of each set of metamorphic strata twofold — Test of age by fossils and mineral character not available — Test by superposition ambiguous—Conversion of dense masses of fossiliferous strata into metamorphic rocks — Limestone and shale of Carrara — Metamorphic strata of modern periods in the Alps of Switzerland and Savoy — Why the visible crystalline strata are none of them very modern — Order of succession in metamorphic rocks — Uniformity of mineral character—Why the metamorphic strata are less calcareous than the fossiliferous — Concluding remarks.

According to the theory adopted in the last chapter, the age of each set of metamorphic strata is twofold, they have been deposited at one period, they have become crystalline at another. We can rarely hope to define with exactness the date of both these periods, the fossils having been destroyed by plutonic action, and the mineral characters being the same, whatever the age. Superposition itself is an ambiguous test, especially when we desire to determine the period of crystallization. Suppose, for example, we are convinced that certain metamorphic strata in the Alps, which

are covered by cretaceous beds, are altered lias; this lias may have assumed its crystalline texture in the cretaceous or in some tertiary period, the Eocene for example. If in the latter, it should be called Eocene, when regarded as a metamorphic rock, although it be liassic, when considered in reference to the era of its deposition. According to this view, the superposition of chalk does not prevent the subjacent *metamorphic* rock from being Eocene. If, however, in the progress of science, we should succeed in ascertaining the twofold chronological relations of the metamorphic formations, it might be useful to adopt a twofold terminology. We might call the strata above alluded to Liassic-Eocene, or Liassic-Cretaceous; the first term referring to the era of deposition, the second to that of crystallization. According to this method, the chlorite-schist, mica-schist, and gneiss of the Malvern Hills, would belong to the Silurian-Old Red sandstone period, because they are Silurian strata altered into metamorphic rocks during the deposition of the Old Red sandstone. (See p. 365.)

We have seen, when discussing the ages of the plutonic rocks, that examples occur of various primary, secondary, and tertiary deposits converted into metamorphic strata, near their contact with granite. There can be no doubt in these cases that strata, once composed of mud, sand,

and gravel, or of clay, marl, and shelly limestone, have for the distance of several yards, and in some instances several hundred feet, been turned into gneiss, mica-schist, hornblende-schist, chlorite-schist, quartz rock, statuary marble, and the rest. (See the two preceding Chapters.)

But when the metamorphic action has operated on a grander scale, it tends entirely to destroy all monuments of the date of its development. It may be easy to prove the identity of two different parts of the same stratum; one, where the rock has been in contact with a volcanic or plutonic mass, and has been changed into marble or hornblende-schist, and another not far distant, where the same bed remains unaltered and fossiliferous; but when we have to compare two portions of a mountain chain — the one metamorphic, and the other unaltered — all the labour and skill of the most practised observers are required. I shall mention one or two examples of alteration on a grand scale, in order to explain to the student the kind of reasoning by which we are led to infer that dense masses of fossiliferous strata have been converted into crystalline rocks.

Northern Apennines.—Carrara.—The celebrated marble of Carrara, used in sculpture, was once regarded as a type of primitive limestone. It abounds in the mountains of Massa Carrara, or

the "Apuan Alps," as they have been called, the highest peaks of which are nearly 6000 feet high. Its great antiquity was inferred from its mineral texture, from the absence of fossils, and its passage downwards into talc-schist and garnetiferous mica-schist; these rocks again graduating downwards into gneiss, which is penetrated, at Forno, by granite veins. Now the researches of MM. Savi, Boué, Pareto, Guidoni, De la Beche, and especially Hoffmann, have demonstrated that this marble, once supposed to be formed before the existence of organic beings, is, in fact, an altered limestone of the Oolitic period, and the underlying crystalline schists are secondary sandstones and shales, modified by plutonic action. In order to establish these conclusions it was first pointed out, that the calcareous rocks bordering the Gulf of Spezia, and abounding in Oolitic fossils, assume a texture like that of Carrara marble, in proportion as they are more and more invaded by certain trappean and plutonic rocks, such as diorite, euphotide, serpentine, and granite, occurring in the same country.

It was then observed that, in places where the secondary formations are unaltered, the uppermost consist of common Apennine limestone with nodules of flint, below which are shales, and at the base of all, argillaceous and siliceous sandstones. In the limestone, fossils are frequent, but very rare in the underlying shale and sandstone. Now

a gradation has been traced laterally from these rocks into another and corresponding series, which is completely metamorphic; for at the top of this we find a white granular marble, wholly devoid of fossils, and almost without stratification, in which there are no nodules of flint, but in its place siliceous matter disseminated through the mass in the form of prisms of quartz. Below this, and in place of the shales, are talc-schists, jasper, and hornstone; and at the bottom, instead of the siliceous and argillaceous sandstones, are quartzite and gneiss.* Had these secondary strata of the Apennines undergone universally as great an amount of transmutation, it would have been impossible to form a conjecture respecting their true age; and then, according to the common method of geological classification, they would have ranked as primary rocks. In that case the date of their origin would have been thrown back to an era antecedent to the deposition of the Lower Cambrian strata, although in reality they were formed in the Oolitic period, and altered at some subsequent and unknown epoch.

Alps of Switzerland. — In the Alps, analogous conclusions have been drawn respecting the alteration of strata on a still more extended scale.

* See notices of Savi, Hoffmann, and others, referred to by Boué, Bull. de la Soc. Géol. de France, tom. v. p. 317; and tom. iii. p. xliv.

In the eastern part of that chain, some of the primary fossiliferous strata, as well as the older secondary formations, together with the oolitic and cretaceous rocks, are distinctly recognizable. Tertiary deposits also appear in a less elevated position on the flanks of the Eastern Alps; but in the Central or Swiss Alps, the primary fossiliferous, and older secondary formations disappear, and the Cretaceous, Oolitic, and Liassic strata graduate insensibly into metamorphic rocks, consisting of granular limestone, talc-schist, talcose-gneiss, micaceous schist, and other varieties. In regard to the age of this vast assemblage of crystalline strata, we can merely affirm that some of the upper portions are altered newer secondary deposits: but we cannot avoid suspecting that the disappearance both of the older secondary and primary fossiliferous rocks may be owing to their having been all converted in this region into crystalline schist.

It is difficult to convey to those who have never visited the Alps a just idea of the various proofs which concur to produce this conviction. In the first place, there are certain points were strata of the Oolite, Lias, and Chalk have been turned into granular marble, gneiss, and other metamorphic schists, near their contact with granite. This fact shows undeniably that plutonic causes continued to be in operation in the Alps down to a late

period, even after the deposition of some of the newer secondary formations. Having established this point, we are the more willing to believe that many inferior fossiliferous rocks, probably exposed for longer periods to a similar action, may have become metamorphic to a still greater extent.

We also discover in parts of the Swiss Alps dense masses of strata of the age of the Green-sand and Chalk, which have assumed that semi-crystalline texture which Werner called transition, and which naturally led his followers, who attached great importance to mineral characters taken alone, to class them as transition formations, or as groups older than the lowest secondary rocks. (See Vol. I. p. 187.) Now, it is probable that these strata have been affected, although in a less intense degree, by that same plutonic action which has entirely altered and rendered metamorphic so many of the subjacent formations; for in the Alps, this action has by no means been confined to the immediate vicinity of granite. Granite, indeed, and other plutonic rocks rarely make their appearance at the surface, notwithstanding the deep ravines which lay open to view the internal structure of these mountains. That they exist below at no great depth we cannot doubt, and we have already seen (p. 341) that at some points, as in the Valorsine, near Mont Blanc, granite and granitic veins are observable, piercing through talcose

gneiss, which passes insensibly upwards into secondary strata.

It is certainly in the Alps of Switzerland and Savoy, more than in any other district in Europe, that the geologist is prepared to meet with the signs of an intense development of plutonic action; for here we find the most stupendous monuments of mechanical violence, by which strata thousands of feet thick have been bent, folded, and overturned. (See Vol. I. p.124.) It is here that marine secondary formations of a comparatively modern date, such as the Oolitic and Cretaceous, have been upheaved to the height of 10,000, or even 12,000 feet above the level of the sea; and even tertiary strata, apparently of the Miocene era, have been raised to an elevation of 4000 or 5000 feet, so as to rival in height the loftiest mountains in Great Britain.

If the reader will consult the works of many eminent geologists who have explored the Alps, especially those of MM. De Beaumont, Studer, Necker, and Boué, he will learn that they all share, more or less fully, in the opinions above expressed. It has, indeed, been stated by MM. Studer and Hugi, that there are complete alternations on a large scale of secondary strata, containing fossils, with gneiss and other rocks, of a perfectly metamorphic structure. I have visited some of the most remarkable localities referred to by these

authors; but, although agreeing with them that there are passages from the fossiliferous to the metamorphic series far from the contact of granite or other plutonic rocks, I was unable to convince myself that the distinct alternations of highly crystalline, with unaltered strata above alluded to, might not admit of a different explanation. In one of the sections described by M. Studer in the highest of the Bernese Alps, namely in the Roththal, a valley bordering the line of perpetual snow on the northern side of the Jungfrau, I observed a mass of gneiss 1000 feet thick, and 15,000 feet long, not only resting upon, but also again covered by strata containing oolitic fossils. These anomalous appearances may partly be explained by supposing great solid wedges of intrusive gneiss to have been forced in laterally between strata to which I found them to be in many sections unconformable. The superposition, also, of the gneiss to the oolite may, in some cases, be due to a reversal of the original position of the beds in a region where the convulsions have been on so stupendous a scale.

On the Sattel also, at the base of the Gestellihorn, above Enzen, in the valley of Urbach, near Meyringen, some of the intercalations of gneiss between fossiliferous strata may, I conceive, be ascribed to mechanical derangement. Almost any hypothesis of repeated changes of position

may be resorted to in a region of such extraordinary confusion. The secondary strata may first have been vertical, and then certain portions may have become metamorphic (the plutonic influence ascending from below) while intervening strata remained unchanged. The whole series of beds may then again have been thrown into a nearly horizontal position, giving rise to the superposition of crystalline upon fossiliferous formations.

It was remarked, in the 33d chapter, that as the hypogene rocks, both stratified and unstratified, crystallize originally at a certain depth beneath the surface, they must always, before they are upraised and exposed at the surface, be of considerable antiquity, relatively to a large portion of the fossiliferous and volcanic rocks. They may be forming at all periods; but before any of them can become visible, they must be raised above the level of the sea, and some of the rocks which previously concealed them must have been removed by denudation. If the student will refer to the frontispiece, he will see that the strata A, which were the last deposited, are every where hidden from human observation by the sea, while the contemporaneous metamorphic rocks C are concealed at a still greater depth, as are also the plutonic rocks D of the same age. He will also observe that the strata C, which have recently become metamorphic, are not parts of A, nor

even of the groups immediately antecedent in date *a*, *b*, *c*, but they are portions of much older formations, *d*, *e*, *f*, *g*, *h*, *i*. Now, suppose that part of the earth's crust, which is represented in the frontispiece to be subjected, in various places, to a long series of upheaving and depressing movements; the beds A will, here and there, be partially upraised and converted into dry land, but the hypogene rocks C, D, although brought up nearer to the surface, will still, very probably, remain hidden from sight. Let a second period elapse and the rocks A may be raised in some countries to a height of several thousand feet; and still the rocks C and D may be almost every where hidden. During a third period, when the stratified formations A have been laid dry over large continental areas, and have reached the summits of some Alpine chains, the hypogene formations C D may also be forced up and exposed to view above the level of the ocean by similar causes; but they will rank no longer as modern rocks, because newer groups, both fossiliferous and volcanic, would have been formed subsequently to their origin. The student will also perceive how impossible it may then be to prove that the strata C became metamorphic at the period of the deposition of A, and how difficult not to exaggerate the antiquity of C as a series of metamorphic rocks, when the remote

period of their deposition has been ascertained, and the comparatively modern era of their crystallization remains uncertain.

Order of succession in metamorphic rocks. — There is no universal and invariable order of superposition in metamorphic rocks, although a particular arrangement may prevail throughout countries of great extent, for the same reason that it is traceable in those sedimentary formations from which crystalline strata are derived. Thus, for example, we have seen that in the Apennines, near Carrara, the descending series, where it is metamorphic, consists of, 1st, saccharine marble; 2dly, talcose-schist; and 3dly, of quartz-rock and gneiss; where unaltered, of, 1st, fossiliferous limestone; 2dly, shale; and 3dly, sandstone.

But if we investigate different mountain chains we find gneiss, mica-schist, hornblende-schist, chlorite-schist, hypogene limestone, and other rocks, succeeding each other, and alternating with each other, in every possible order. It is, indeed, more common to meet with some variety of clay-slate forming the uppermost member of a metamorphic series than any other rock; but this fact by no means implies, as some have imagined, that all clay-slates were formed at the close of an imaginary period, when the deposition of the crystalline strata gave way to that of ordinary sedimentary deposits. Such clay-slates, in fact, are

variable in composition, and sometimes alternate with fossiliferous strata, so that they may be said to belong almost equally to the sedimentary and metamorphic order of rocks. It is probable that had they been subjected to more intense plutonic action, they would have been transformed into hornblende-schist, foliated chlorite-schist, scaly talcose-schist, mica-schist, or other more perfectly crystalline rocks, such as are usually associated with gneiss.

Uniformity of mineral character in Hypogene rocks. — Humboldt has emphatically remarked that when we pass to another hemisphere, we see new forms of animals and plants, and even new constellations in the heavens; but in the rocks we still recognize our old acquaintances, — the same granite, the same gneiss, the same micaceous schist, quartz-rock, and the rest. It is certainly true that there is a great and striking general resemblance in the principal kinds of hypogene rocks, although of very different ages and countries; but it has been shown that each of these are, in fact, geological families of rocks, and not definite mineral compounds. They are much more uniform in aspect than sedimentary strata, because these last are often composed of fragments varying greatly in form, size, and colour, and contain fossils of different shapes and mineral composition, and acquire a variety of tints from the mixture of various

kinds of sediment. The materials of such strata, if melted and made to crystallize, would be subject to chemical laws, simple and uniform in their action, the same in every climate, and wholly undisturbed by mechanical and organic causes.

Nevertheless, it would be a great error to assume that the hypogene rocks, considered as aggregates of simple minerals, are really more homogeneous in their composition than the several members of the sedimentary series. In the first place, different assemblages of hypogene rocks occur in different countries; and, secondly, in any one district, the rocks which pass under the same name are often extremely variable in their component ingredients, or at least in the proportions in which each of these are present. Thus, for example, gneiss and mica-schist, so abundant in the Grampians, are wanting in Cumberland, Wales, and Cornwall; in parts of the Swiss and Italian Alps, the gneiss and granite are talcose, and not micaceous, as in Scotland; hornblende prevails in the granite of Scotland — schorl in that of Cornwall — albite in the plutonic rocks of the Andes — common felspar in those of Europe. In one part of Scotland, the mica-schist is full of garnets; in another it is wholly devoid of them: while in South America, according to Mr. Darwin, it is the gneiss, and not the mica-schist, which is most commonly garnetiferous. And not only do the proportional quantities of

felspar, quartz, mica, hornblende, and other minerals, vary in hypogene rocks bearing the same name; but what is still more important, the ingredients, as we have seen, of the same simple mineral are not always constant. (p. 191., and table, p. 210.)

The Metamorphic strata, why less calcareous than the fossiliferous.—It has been remarked, that the quantity of calcareous matter in metamorphic strata, or, indeed, in the hypogene formations generally, is far less than in fossiliferous deposits. Thus the crystalline schists of the Grampians in Scotland, consisting of gneiss, mica-schist, hornblende-schist, and other rocks, many thousands of yards in thickness, contain an exceedingly small proportion of interstratified calcareous beds, although these have been the objects of careful search for economical purposes. Yet limestone is not wanting in the Grampians, and it is associated sometimes with gneiss, sometimes with mica-schist, and in other places with other members of the metamorphic series. But where limestone occurs abundantly, as at Carrara, and in parts of the Alps, in connection with hypogene rocks, it usually forms one of the superior members of the crystalline group.

The scarcity, then, of carbonate of lime in the plutonic and metamorphic rocks generally, seems to be the result of some general cause.

So long as the hypogene rocks were believed to have originated antecedently to the creation of organic beings, it was easy to impute the absence of lime to the non-existence of those mollusca and zoophytes by which shells and corals are secreted; but when we ascribe the crystalline formations to plutonic action, it is natural to inquire whether this action itself may not tend to expel carbonic acid and lime from the materials which it reduces to fusion or semi-fusion. Although we cannot descend into the subterranean regions where volcanic heat is developed, we can observe in regions of spent volcanos, such as Auvergne and Tuscany, hundreds of springs both cold and thermal, flowing out from granite and other rocks, and having their waters plentifully charged with carbonate of lime. The quantity of calcareous matter which these springs transfer, in the course of ages, from the lower parts of the earth's crust to the superior or newly formed parts of the same, must be considerable.*

If the quantity of siliceous and aluminous ingredients brought up by such springs were great, instead of being utterly insignificant, it might be contended that the mineral matter thus expelled implies simply the decomposition of ordinary subterranean rocks; but the prodigious excess of car-

* See Principles, *Index*, "Calcareous Springs."

bonate of lime over every other element must, in the course of time, cause the crust of the earth below to be almost entirely deprived of its calcareous constituents, while we know that the same action imparts to newer deposits, ever forming in seas and lakes, an excess of carbonate of lime. Calcareous matter is poured into these lakes, and the ocean, by a thousand springs and rivers; so that part of almost every new calcareous rock chemically precipitated, and of many reefs of shelly and coralline stone, must be derived from mineral matter subtracted by plutonic agency, and driven up by gas and steam from fused and heated rocks in the bowels of the earth.

Not only carbonate of lime, but also free carbonic acid gas is given off plentifully from the soil and crevices of rocks in regions of active and spent volcanos, as near Naples, and in Auvergne. By this process, fossil shells or corals may often lose their carbonic acid, and the residual lime may enter into the composition of augite, hornblende, garnet, and other hypogene minerals. That the removal of the calcareous matter of fossil shells is of frequent occurrence, is proved by the fact of such organic remains being often replaced by silex or other minerals, and sometimes by the space once occupied by the fossil being left empty, or only marked by a faint impression. We ought not indeed to marvel at the general absence of organic

remains from the crystalline strata, when we bear in mind how often fossils are obliterated, wholly or in part, even in tertiary formations — how often vast masses of sandstone and shale, of different ages, and thousands of feet thick, are devoid of fossils — how certain strata may first have been deprived of a portion of their fossils when they became semi-crystalline, or assumed the *transition* state of Werner — and how the remaining organic remains have been effaced when they were rendered metamorphic. Some rocks of the last-mentioned class, moreover, must have been exposed again and again to renewed plutonic action.

Concluding Remarks. — The theory of the origin of the hypogene or metamorphic strata, at a variety of successive periods, as expounded in this chapter, and still more the doctrine that such rocks may be now in the daily course of formation, has made and still makes its way, but slowly, into favour. The disinclination to embrace it has arisen partly from an inherent obscurity in the very nature of the evidence of plutonic action when developed on a great scale, at particular periods. It has also sprung, in some degree, from extrinsic considerations; many geologists having been unwilling to believe the doctrine of

the transmutation of fossiliferous into crystalline rocks, because they were desirous of finding proofs of a beginning, and of tracing back the history of our terraqueous system to times anterior to the creation of organic beings. But if these expectations have been disappointed, if we have found it impossible to assign a limit to that time throughout which it has pleased an Omnipotent and Eternal Being to manifest his creative power, we have at least succeeded beyond all hope in carrying back our researches to times antecedent to the existence of man. We can prove that man had a beginning, and that all the species now contemporary with man, and many others which preceded, had also a beginning, and that, consequently, the present state of the organic world has not gone on from all eternity, as some philosophers had maintained.

It can be shown that the earth's surface has been remodelled again and again; mountain chains have been raised or sunk; valleys formed, filled up, and then re-excavated; sea and land have changed places; yet throughout all these revolutions, and the consequent alterations of local and general climate, animal and vegetable life has been sustained. This has been accomplished without violation of the laws now governing the organic creation, by which limits are assigned to the variability of species.

The succession of living beings appears to have been continued not by the transmutation of species, but by the introduction into the earth from time to time of new plants and animals, and each assemblage of new species must have been admirably fitted for the new states of the globe as they arose, or they would not have increased and multiplied and endured for indefinite periods.*

Astronomy had been unable to establish the plurality of habitable worlds throughout space, however favourite a subject of conjecture and speculation; but geology, although it cannot prove that other planets are peopled with appropriate races of living beings, has demonstrated the truth of conclusions scarcely less wonderful, — the existence on our own planet of so many habitable surfaces, or worlds as they have been called, each distinct in time, and peopled with its peculiar races of aquatic and terrestrial beings.

The proofs now accumulated of the close analogy between extinct and recent species are such as to leave no doubt on the mind that the same harmony of parts and beauty of contrivance which we admire in the living creation, has equally characterized the organic world at remote periods. Thus as we increase our knowledge of the inexhaustible variety displayed in living nature, and admire the

* See Principles of Geol., Book 3.

infinite wisdom and power which it displays, our admiration is multiplied by the reflection, that it is only the last of a great series of pre-existing creations, of which we cannot estimate the number or limit in times past.*

* See the author's Anniv. Address to the Geol. Soc. 1837. Proceedings of G. S., No. 49. p. 520.

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